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1872

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PREFACE.

THIS work forms the first part of CHAMBERS'S CLASS-BOOK OF SCIENCE AND LITERATURE. It embraces original lessons on PHYSICS, HUMAN PHYSIOLOGY, ZOOLOGY, GEOLOGY, and BOTANY. Each of these subjects is illustrated by wood-cuts, and the Geology is accompanied by a Geological Map of the British Islands. All technical terms are explained, and their derivation given.

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PHYSICS.

Introductory.

Physics or Physical Science, from the Greek word *physis*, nature, was the name originally applied to the whole of man's knowledge regarding *Nature* or the material universe. The universe is composed of an immense variety of materials or objects, many of which bear a general resemblance to each other. This resemblance has led to a classification of these materials into three Kingdoms—the Animal, the Vegetable, and the Mineral; and the minute description of these classes constitutes the science of Natural History. Besides this resemblance between particular objects, it has been found that certain motions or changes, called *phenomena* [Gr., 'appearances'], are continually going on among the objects themselves. And as, for convenience, the materials of the universe have been arranged under separate classes, there is likewise a classification of the phenomena to which they are subject. There is one class of phenomena which are always accompanied by a very decided change in the bodies themselves: the science which treats of these phenomena is called Chemistry. A second class, caused by the action of *Life*, is included under the science of Physiology. A third class is formed of those phenomena which are caused by the action of *Mind:* these belong to the science of Mental Philosophy. The fourth and last class of phenomena includes those which are neither accompanied by any essential change in the object, nor caused by the action of life or of mind, but which are due simply to the properties of bodies as bodies, and are common to all objects, animate or inanimate. It is to the knowledge of this last class of phenomena that the name of Physics, Physical Science, or Natural Philosophy is now properly applied.

Properties of Matter.

Under the name of Matter is included everything that we become acquainted with by means of our senses. Farther on, Matter will be treated of under the forms, Solid, Liquid, and Gaseous; but there are certain properties, common to all kinds of matter, which must first be described.

1. **Extension or Magnitude.**—Extension or magnitude is the property of matter which implies that it *is extended* or occupies room or space. Bodies are extended in three directions, or have three *dimensions* or measures—length, breadth, and depth. Width is another term used for breadth; and for depth we often use height, and sometimes thickness. By these three dimensions the *shape* of a body is determined. If we think of a stone, it may be round or square; or if of a mountain, it may be high or low; but it will have some shape. When we speak of the size of anything, we can do so only by comparing it with something else, the size of which we do know; for example, a boy describes something to his friend as being as big as his fist, or as big as his head. For the sake of convenience, standards of measurement have been fixed upon to be used by all. For length, the inch is the standard; and we say a thing is so many inches or so many feet long. For measuring a surface, which has both length and breadth, the standard is a small square an inch long and an inch broad, called a square inch; and a surface is said to contain so many square inches, or so many square feet. Lastly, for solids, which have length, breadth, and depth, the standard is a small cube, each side of which is a square inch; and the bulk or volume of any quantity of matter is said to be so many cubic inches or so many cubic feet.

2. **Impenetrability.**—The word impenetrability must have a peculiar meaning here, for there is no material so hard that it could not be *penetrated* or pierced, if proper instruments were used. Impenetrability, as applied to matter, means simply that *two bodies cannot be in the same place at the same time.* A nail can be driven into wood, but it is impossible that there can be wood in the very space occupied by the nail: the particles of the wood are merely forced more closely together, in order to make room for it. This property of matter is obvious in regard to solid bodies, but it is not so obvious with regard to fluids. Common air offers so little obstruction to our movements, that we are apt to forget that it is a real material body. That it is so, can be shewn by many simple illustrations. When a bladder is filled with air, it is impossible to press the sides together without bursting the bladder. If a tumbler be put, mouth downwards, into a vessel full of water, the water does not fill the tumbler completely, because it is prevented from doing so by the

air in the tumbler. This property of air is taken advantage of in the diving-bell. That a liquid cannot occupy the same space with any other body, is clear from the fact, that if anything be put into a vessel full of water, the water will flow over, so as to make room for the body put in.

3. **Divisibility.**—The nature of matter is such that it can be divided to an extent far beyond the limits perceptible to the senses. A grain of gold, the bulk of which is one five-thousandth part of a cubic inch, can be beaten out so as to cover 57 square inches. The leaf thus formed is so thin that a pile an inch thick would contain 282,000 leaves. The microscope has revealed the existence of animals, a million of which would not occupy more space than a grain of sand. Yet these animalcules, as they are called, have members and organs, and display all the appearances of vitality. How shall we conceive the smallness of the tubes or vessels in which their fluids circulate, and the minuteness of the particles of matter composing these tubes and fluids! It must not, however, be supposed that there is no limit to the divisibility of matter. On the contrary, there are many reasons for believing that there is a limit somewhere; and that there are ultimate particles of a determinate size and shape, incapable of further subdivision. These assumed particles are called *atoms* [Gr. *atomos*, from *a*, not, *temnō*, to cut].

4. **Cohesion.**—Cohesion is the property by which the particles of matter *stick together* and form masses or bodies. Without this force to bind its particles together, matter would only exist in the shape of sand or powder. There is another kind of attraction, called the Attraction of Gravitation, by which one body acts upon every other body at any distance, however great; but cohesion acts only when the particles are in contact, or when the distances between them are imperceptible. Thus, when a stone is broken, the fragments cannot be made to adhere, although placed together again; in other words, the cohesion which existed between the particles before will not operate after they have been separated. The degree of cohesion in all bodies, however, is not the same; and this gives rise to what are called *states of aggregation* of particles, of which there are three—*the solid*, *the liquid*, and *the gaseous*.

When the air has been entirely drawn out of a vessel by an air-pump, and a small quantity of gas introduced, the gas does not remain of the same bulk, but spreads itself throughout the whole vessel. This proves that there is in the gas itself a force repelling the particles with a power sufficient to overcome their own weight. This force was formerly called *Repulsion*, but it is now known that it is not an essential property, but the effect of heat, which is a form of motion among the particles. In addition to the cohesive force which binds the particles of matter together, there is thus another which repels them from each other. When the cohesion is greater than the repulsion, the body is firm and

solid; when the cohesion and repulsion seem to be equal, the particles are less firmly united, are freely movable among one another, and the body is said to be *liquid;* when the repulsion is greater than the cohesion, the particles are still more freely movable than in liquids, and such bodies are called *gases.*

Certain names have been applied to different states of cohesion:

(1) *Tenacity* is the quality by which a body resists being torn asunder, and depends on the intensity of the cohesive force. An iron wire one-tenth of an inch in thickness will sustain a weight of 700 pounds. Fibrous substances, as silk and flax, possess great tenacity. The most tenacious of all substances is steel.

(2) *Malleability* means the capability possessed by some metals, as gold, silver, copper, &c. of being *hammered out* into thin plates. This quality depends on the union of softness and tenacity in the bodies possessing it; being soft, their particles can be made to change their position with regard to one another; being tenacious, the particles will not readily separate.

(3) *Ductility*, the capability possessed by a metal of being *drawn out* into wire, is of the same nature as Malleability, both depending on a certain degree of softness and great tenacity. These properties are not, however, identical, for the most malleable metals are not the most ductile. The most malleable metal is gold; the most ductile, platinum.

(4) *Hardness.*—Both in malleable and in hard bodies, the force with which the particles stick together is very great. In a malleable body the particles can be made to change their position by sliding or rolling on one another without separating, while in a hard body they resist change of position, and, if forced, separate or break. The relative hardness of two bodies is ascertained by trying which of them will scratch the other. Thus glass will scratch gold, and even platinum. All precious stones are very hard. The diamond is the hardest substance known, and is used in cutting glass.

(5) *Brittleness* is closely allied to hardness, for most hard bodies are brittle. It would seem to be the opposite of Malleability, for on a very slight attempt to displace the position of the particles, the body flies in pieces. Glass has this property to a remarkable degree.

The five properties enumerated above are due to certain states of the cohesion of the particles of a single solid body; there is also an attraction between two different bodies, which makes them stick to each other by their surfaces. This attraction is called *adhesion.*

5. **Adhesion.**—(1) *Adhesion between two solids.*—If two lead bullets be taken, and a piece be cut off each, leaving perfectly smooth surfaces, the bullets will stick together when these two surfaces are joined; or if two pieces of glass be laid upon each other, they stick together with considerable force. (2) *Adhesion between a solid and a liquid* is seen

whenever a solid which has been put in a liquid comes out *wet*. This attraction affords an explanation of what often happens when water is poured from a vessel—the water runs down the outside of the vessel, instead of flowing as desired. (3) *Adhesion between solids and gases.*—If a piece of cork be pushed down into water, little air-bubbles are seen sticking to it. When a lump of sugar is dropped into a cup of tea, the atmosphere of air which surrounds the particles does not quit them till they are dissolved; bubbles are seen rising till all the sugar has disappeared.

6. **Porosity.**—Looking at a piece of cork or of sponge, we see that it is full of little holes; these holes are called *pores*, and the substances having these holes are said to be *porous*. In ordinary language, it is only such substances as cork and very soft woods, in which these little holes are visible, that are said to have pores; but, in reality, all substances are more or less porous. When a piece of bone is examined with a microscope, it appears almost like a pile of empty boxes; and a piece of wood appears like a bundle of pipes. Even the densest solids, as gold and silver, have been proved to be porous. Thus, when a hollow sphere of silver was filled with water, and squeezed with great force, the water oozed through the silver, and stood in drops on the outside of the sphere.

7. **Density.**—This property is very closely connected with porosity: the two are, in fact, the converse of each other, because the more porous a body is, it is the less dense. If we squeeze a body to half its former size, there is of course no less matter in it, but we say we have doubled its *density*, while we have reduced it to half its original *volume;* so that there are in the body after being compressed more atoms (that is, more matter) in the same space than there were before. In comparing the density of different substances, the density of water (distilled) is taken as a standard, and called 1. Measured by this standard, the density of other bodies is called their *Specific Gravity:* thus, the specific gravity of a body whose density is double that of water is said to be 2. Density is a very variable property: it is often increased owing to the *Compressibility* of bodies, and as often lessened by their *Dilatability*. An iron rod when heated becomes both thicker and longer, and contracts again with cold. So much is this the case, that when measurements are being made with an iron rod or chain, if the chain be exposed to great heat or cold, allowance must be made for difference of length. The iron rims of wheels could not be made to fit so tightly, were it not that they are put on when hot. Being a perfect fit when hot, when the iron cools and contracts, the rim binds the wheel very closely. Gases are also highly dilatable. If a bladder be filled almost full of cold air, so as to shew the bladder loose and wrinkled, when heated it is seen to swell out and become quite tight, from the air expanding: on the other hand, many cubic feet of air may be compressed into a single inch.

8. **Elasticity.**—This property is intimately connected with porosity and density. We have seen that bodies are both compressible and dilatable; now, some bodies when compressed have a natural tendency, when the pressure is removed, to expand again to their original volume; such bodies are said to be *elastic*, while those that retain the form given them by the compressing force are called *non-elastic*. Elasticity is not confined, however, to bodies that may be compressed like a piece of sponge, but those bodies are also said to be elastic, which return to the state or position in which they were before the force changing them was applied. A steel spring, when it is bent and then let go, immediately springs back to its former position; so with a piece of india-rubber when stretched. The most elastic of all bodies are gases. The air-gun affords a very good illustration of the elasticity of common air. At the breech of a gun, with an ordinary barrel, is a small hollow sphere, into which air is forced by an instrument for the purpose until it is very much condensed. The opening by which the air is forced in is closed by a valve which opens inward, and when a shot is to be fired, the cock strikes the valve in, allowing a quantity of the condensed air to escape into a chamber behind the ball; and so great is the elasticity of the air, that the ball is projected from the gun with a force almost equal to that of a charge of gunpowder.

9. **Inertia.**—Inertia is the property which bodies have of always remaining in the same state, till that state be changed by external causes. Bodies at rest will remain always at rest, and bodies in motion will remain always in motion, as far as they themselves are concerned; that is, till they be set in motion or stopped by external causes. No proof is required of the fact that when a body is at rest, it will not begin to move of itself; but it is not so clear that when a body is in motion, it will not stop of itself: indeed, many phenomena seem to prove the contrary. However powerfully a stone may be thrown or rolled along the ground, it will at last come to rest. It would thus seem as if it ceased to move of itself; but the truth is, that two very powerful agents are at work to stop it. These are *the resistance of the air* and *friction*. The resistance of the air is far greater than is generally supposed. On putting one's head out of the window of a railway train, the effect experienced is exactly the same as if a gale of wind were blowing. It has been calculated that a 24-pound cannon-ball, when fired with a velocity of 2000 feet per second, experiences a resistance of 800 pounds. The retarding force of friction is greater even than this. We best see its effect by considering what takes place when it is removed. It is well known that a ball will roll much farther, with the same force, on a smooth floor than on a rough piece of ground, and much farther on a sheet of ice than on either. The smoother the surface, then, on which a

body moves, the longer it continues to move. We also know that when a body, a pendulum for example, is set in motion in a place from which the air has been removed, it continues to move for a very long time. It may therefore be inferred, that if friction and the resistance of the air could be removed altogether, a body would, if once set in motion, continue to move for ever.

Forces and Motion.

It has been shewn in the definition of Inertia that a body, whether at rest or in motion, cannot *itself* alter that state. In order to do so, some external cause is necessary. Such a cause is called a *Force*. Force is thus intimately connected with motion; for, if a body be at rest, a force is necessary to set it in motion; and, if it be in motion, a force is necessary to bring it to rest. The principles connecting force and motion have been expressed in three laws, called the Laws of Motion.

First Law of Motion.—The first law of motion is simply a more precise definition of Inertia. *A body will remain either in a state of rest, or in a state of uniform motion in a straight line, unless compelled to change that state by some external force.*

The next consideration that naturally occurs is: How does this change of state depend on the force that produces it? The answer to this question is a statement of the second law of motion, which is as follows:

Second Law of Motion.—*When a body is in motion under the influence of any number of forces, each force produces the same effect as it would if the other forces were not acting.*

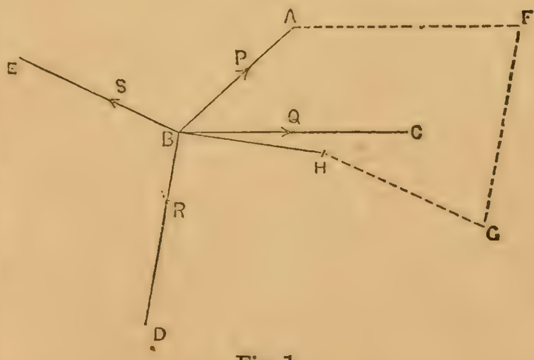


Fig. 1.

Suppose a number of forces, P, Q, R, and S, to be acting on a body B; each of these forces, if it were acting by itself, would move the body a certain distance, proportioned to its strength, and in its own direction. Let the lines BA, BC, BD, and BE represent the forces P, Q, R, and S in direction and magnitude. If P alone were acting on the body, it would be moved to A; if, then, Q were to act on it, it would move along AF, parallel to BC, and to a distance from A equal to BC. Let AF be equal to BC; and if, when the body was at F, it were acted upon by R, it would move from F to G, FG being equal and parallel to BD; and so from G to H, GH being equal and parallel to BE. If acted on by the single forces in succession, then, the body would arrive

at H, moving in the manner described; if they all acted at once, the body would still arrive at H, but only by passing from B to H. A boat being rowed across a river affords a good illustration of this law. If the head of the boat be kept always pointing right across the stream, the passage will be made exactly in the same time as if it had been across a pond of the same breadth; but it will be found that the boat has floated down the stream just as far as it would have done had it been simply floating on the stream for the same time.

In describing the second law of motion, we have spoken only of the effect produced on a body by a force acting upon it; but there is also another effect to be noticed in such cases. If a stone rolled along the ground come in contact with another, the latter will of course be dashed onward, but a change will also take place in the motion of the former; it will either be stopped entirely, or be dashed to one side, or will continue to move in the same direction as before, but with less force. The effect of the rolling stone on the stone at rest is called the *action*, and that of the stone at rest on the rolling one, the *reaction*.

Third Law of Motion.—*To every action there is always an equal and contrary reaction; or, the mutual actions of any two bodies are always equal, and oppositely directed in the same straight line.* If a person in a boat push another boat lying alongside, both boats are moved almost equally from where they were floating, thus shewing that the pushing *reacts* on the one boat as much as it *acts* on the other.

The force with which a body moves is called its *momentum*, and depends on the *weight* of the body, and the *velocity* with which it is moving. A stone when rolled or thrown has greater force than a ball of wood of the same size would have, because the one is heavier than the other; similarly, a large stone has greater force than a smaller one. Instead of *weight*, it is more proper to speak of the *mass* of a body; and in order to understand the meaning of *mass*, it is only necessary to remember the definition of 'density;' for to say that a stone is denser than a piece of wood is the same thing as to say that it has more mass than a piece of wood of the same size. If a single atom of matter were moving at the rate of one foot per second, and if we take this as the measure of momentum, then, in a mass of many atoms, the momentum would be measured by the number of atoms; and if this mass were to move at the rate of 100 feet per second, its velocity would be 100 times the number of atoms greater than that of the single atom. The *momentum* of a body is therefore measured by *the mass multiplied by the velocity.*

The Mechanical Powers.

A machine is an instrument by means of which force is applied to the performance of work, generally by changing the direction of the force—as the capstan, by which sailors raise the anchor; the crane, by which stones or other heavy weights are raised; or the lever, by which a heavy object is moved *upwards* by pressing *down* the other end. Such contrivances do not increase the force applied, but merely afford the means by which it may be directed more advantageously to the end in view. The simple machines used for this purpose, or the MECHANICAL POWERS, as they have been called, are usually considered to be six in number—the Lever, the Wheel and Axle, the Pulley, the Inclined Plane, the Screw, and the Wedge.

I.—The Lever.

A lever, from Latin *levo*, to raise, means *that which raises* or *lifts.* It is a body of any form fixed at a point about which it can move, called *the centre of motion*, or the *fulcrum* [Latin, 'a prop']; thus, when the fire is stirred with a poker, the poker is, for the time being, a lever, and the bar on which it rests is the centre of motion, or fulcrum. Levers are distinguished into three classes.

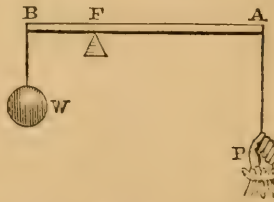


Fig. 2.
AB, the lever; F, the fulcrum; W, the weight; P, the power or force.

(1) The first class of lever (fig. 2) has the fulcrum between the force applied and the weight to be raised, or the resistance to be overcome, as in the case of a poker when stirring the fire. The common balance and a pair of scissors—the latter being double—are both examples of this class of lever.

(2) The second class of lever has the weight between the power and the fulcrum (fig. 3). The common wheelbarrow is a lever of this class; an oar is another example—the man pulling being the power, the water taken hold of by the blade being the fulcrum, and the boat the resistance.

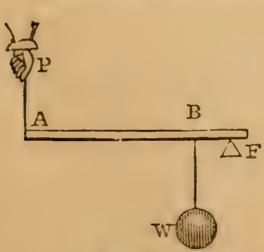


Fig. 3.

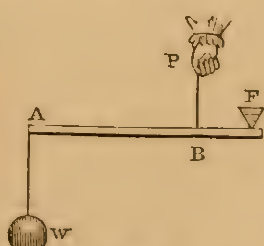


Fig. 4.

(3) The third class of lever has the power between the fulcrum and

the weight (fig. 4). A man pushing open a gate by applying his hand near the hinges, gives an example of a lever of this class; another is furnished by the common fire-tongs, the fulcrum being at the joint, and the lever being double, as in the case of the scissors.

Having now described the different kinds of levers, we proceed to explain the principle upon which they work; and although the practical use of a lever is to *move* a weight, yet, to calculate accurately its manner of working, we must consider it in that state in which the *power balances the weight*, which is called the state of *equilibrium* [Latin, *æquus*, equal, *libra*, a balance]. The whole principle will be understood at once if it be kept in mind that the lever does not, of itself, *give rise* to any force, but merely affords the means of applying it. Let the lever AB (fig. 5), which is three feet long, be supported on the fulcrum F, with two feet of its length on one side, AF, and one foot, FB, on the other; and let a weight of four pounds be suspended at B, and one of two pounds at A. These two weights balance each other—that is, the lever is in equilibrium. But suppose it to move into another position, CD. By a simple proposition in mathematics, we know that AF, being twice as great as FB, the distance AC, through which the small weight moves, is twice as great as BD, the distance through which B moves. We see, then, that the reason why a smaller weight or force is equivalent to a greater weight is, that the smaller force is exerted over a larger space. Thus, when a man wishes to overturn a large stone, and, finding that it is too heavy for him, takes a lever to assist him, he does not get any additional strength from the lever; it merely enables him to concentrate the strength he has. If his strength be sufficient to enable him to press down the end of the lever, the raising power at the other end will be greater exactly in the proportion that the distance through which the one end is pushed down is greater than the distance through which the other end is moved, or in the proportion that the end of the lever next him is longer than the end next the stone. The principle of the lever then is, that the farther from the fulcrum the force is applied, the less it requires to be; and this principle applies to all kinds of levers.

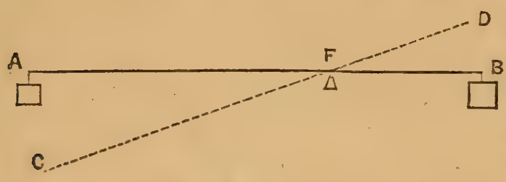


Fig. 5.

Sometimes the object in making use of a lever is not to get a greater power applied, as when a man wishes to raise a stone as described above, but to get greater speed of motion. It will be observed that in fig. 5, the long end of the lever A, since it moves through a distance twice as great as that moved by the short end B, must move twice as fast. If then speed

of motion be desired, it may be gained by means of a lever, *at the expense of a greater force* than is required; and it is to this end that the third kind of lever is applied (see fig. 4). On this principle the foot-board of a turning-lathe is constructed (fig. 6). The fulcrum of the lever is the hinge at the toe of the man's left foot; the power is the man's right foot, which presses down the treadle, thus communicating motion to the string S; and although the power communicated to the string is not so great as that of the pressure of the foot, the velocity is many times greater. Driving nails with a hammer is another example of gain of velocity at the expense of strength or force. The fulcrum is the elbow-joint; the power is exerted by the muscles attached near the wrist; and although the exertion of the muscles is greater than the power communicated to the hammer, yet the velocity gained is very great.

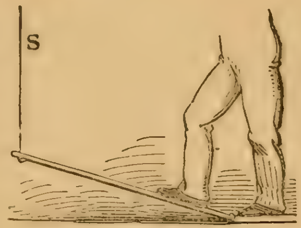


Fig. 6.

The common balance is a familiar application of the lever. Since it is used to weigh quantities of articles *equal* to certain weights, it will be readily understood, from what has been said, that it is absolutely necessary that the arms of the balance be of *equal* length, because a smaller weight at the end of a longer arm would balance a greater weight at the end of a shorter arm. This is one way by which persons selling articles requiring to be weighed could cheat their customers, although their weights were quite correct; for, if one arm of the balance were shorter than the other, by putting the weights at that side, a less quantity than the just weight would balance them.

A few words will now be sufficient to explain the principle of the steelyard, another application of the lever (fig. 7). In the figure, C is the fulcrum or pivot on which it is suspended, CA is the distance from the fulcrum to the point at which the article to be weighed is suspended. The longer arm of the instrument is divided into equal lengths, marked 1, 2, 3, &c.; and the great convenience of this is, that many different quantities can be weighed with one weight. For instance, if the weight used be one pound, and it is required to weigh two pounds, the one-pound weight is placed at the division marked 2, and there, as was seen

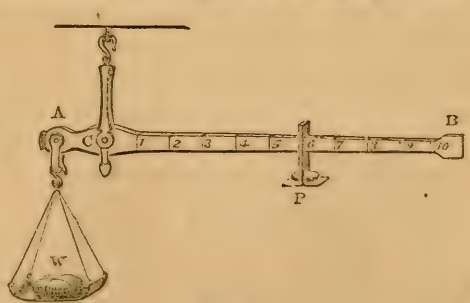


Fig. 7.

in fig. 5, it will balance two pounds in the scale; and so for any other number of pounds, because, if the distance of the small weight from the fulcrum be three, four, or five times greater than the distance of the other weight, that weight must be three, four, or five times greater than the weight at the longer end.

II.—The Wheel and Axle.

This machine, although apparently very different from the lever, is in reality constructed on the same principle. In fig. 8, we see an arrangement by which a small weight, P, balances a much greater one, W. Now, if we

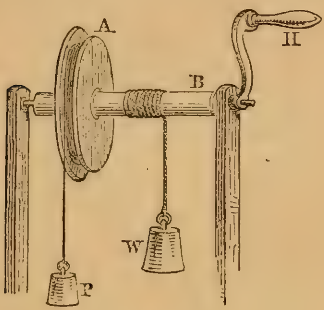


Fig. 8.

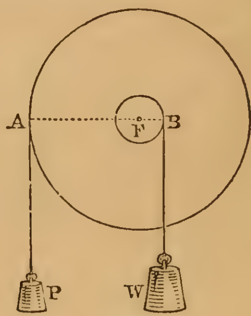


Fig. 9.

take a section of this machine (fig. 9), we see at once how it acts like a lever. Although the machine might be turned round, yet, in every position, the weights act at right angles to the diameters of the wheel and of the axle; and as the machine is perfectly rigid, it is easily seen that it is simply a lever, with F, the centre of the axle, for its fulcrum, and having on one side half the diameter of the wheel, and on the other half the diameter of the axle. If the half-diameter, FA, were six times greater than the half-diameter FB, the weight, P, would balance a weight six times greater than itself. What has been said applies to the machine in a state of equilibrium; for practical purposes, however, the weight on the wheel is not used, the axle being turned by a winch, H (fig. 8). The strength of a man pressing round the handle, acts like the weight on the circumference of the wheel.

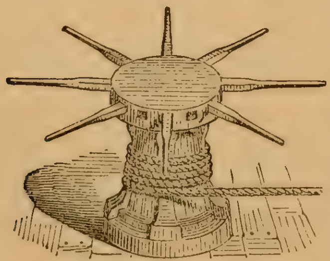


Fig. 10.

The capstan, used on board ships for heaving the anchor, is on the same principle (fig. 10). The fulcrum is the centre of the machine; the short end of the lever, with the heavier weight, is half the diameter of the part round which the

cable is wound; while the longer arm, on which the power acts, is the distance from the centre to the part of the spokes on which the sailors press.

III.—The Pulley.

A pulley consists of a small wheel, with a grooved rim, fixed in a block so as to move freely on its axis, and having a cord passing over the rim, with weights attached to each end. There are two kinds of pulleys, one the fixed pulley, as in fig. 11, the other the movable pulley, as B, fig. 12.

It is clear, that if P is to balance W in fig. 11, the weights must be equal, because the wheel simply acts like a lever with equal arms, as was seen in describing the wheel and axle; so that a fixed pulley does not give any increase of strength, but merely changes the direction of application of the force. For example, if a man wished to raise something heavy to a considerable height, he might find the greatest difficulty in lifting what he could raise with ease by pulling a rope attached to the article over a pulley.

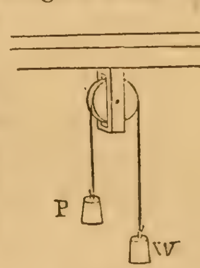


Fig. 11.

By means of a movable pulley, however, as in fig. 12, a man may exert a power greater than his own strength. But, just as in the case of the lever, it is a mistake to suppose that the pulley gives rise to any power in itself; it merely affords the means by which power may be concentrated. The parts of the string in the figure, between A and B, and between B and C, support each one half of the weight of W. And as the effect of C is simply to change the direction of the force, and the tension of the string being the same throughout, it is evident that the hand at P must be pulling with a force equal to half the weight of W. Thus, by means of a movable pulley, a weight or power at the end of a cord is able to balance a weight twice as great. It will readily be seen how it is so. Suppose the cord to be pulled so as to raise W one inch. In order to do this, one inch of cord must be taken up on both sides of the pulley B. The inch on the side of AB will be pulled over the pulley B, and then *two* inches must be pulled over the pulley C; so that, in order to raise W one inch, the hand at P must descend two inches. Thus, exactly as in the case of the lever, although the work done at one end of the machine seems to be greater than that done at the other, it is not really so; for, at the other end, the work is merely spread over a larger space.

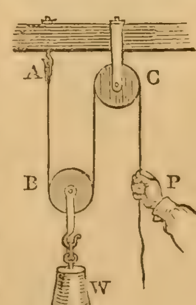


Fig. 12.

IV.—The Inclined Plane.

The Inclined Plane is a contrivance by which a heavy weight can be raised to a height, when it would be difficult or impossible to lift it directly. We have seen, in the case of the Mechanical Powers already considered, that no additional power is actually gained by the use of the machine, or is generated by it, but that its use is simply to enable a small force, when exerted over a larger space, or in a more extended manner, to have the same effect as a greater force applied directly: the same principle applies to the inclined plane. A force pushing a weight from A to B (fig. 13) only raises it through the perpendicular height BD. If, then, AB be twice as long as the height BD, the force necessary to raise any weight from D to B, would, when pushing the weight from A to B, be distributed over twice as much space: but in consequence of this, the force exerted at any moment would be only half as great, leaving out of account the effect of friction, which cannot be taken notice of here. Thus, a power, P, would balance a weight on the plane twice as great; that is, if the mass W weigh two pounds, the weight of P would require to be only one pound. The reason of this is, that part of the weight of W is supported on the plane, so that the resistance of the plane, and the tension of the string, *p*, support the weight of W between them, in the way represented in the figure. The weight of W acts perpendicularly downward from its centre of gravity,[1] *c*, in the direction of *cf*; now, the part of this weight supported by the plane must act perpendicularly to the plane, therefore along *ce*; and the part of it supported by the string, directly opposite to the tension of the string, along *cg*; and these two are independent of each other, so that the proportion of the weight of W to be supported by the string is as *ce* is to *cf*. Now, it is known, according to a simple geometrical problem, that *cg* is

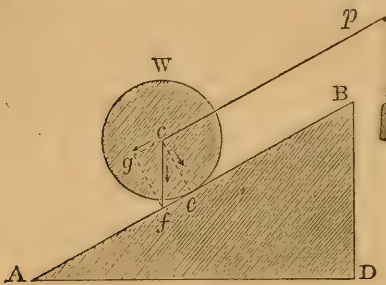


Fig. 13.

Fig. 14.

[1] Centre of gravity is a point in a body such that, if the body be suspended upon that point, it will balance itself in every position.

to *cf* as BD is to AB ; therefore, the force necessary to balance a weight on an inclined plane is proportioned to that weight, as the height of the plane is to its length. The degree of slope in an incline is expressed by saying that there is a rise of one foot in so many feet ; thus, in fig. 14, where AB is ten times BC, the horse is pulling a load up an incline of one in ten. And, according to what has been said, the draught necessary to be exerted by the horse, if the plane be perfectly smooth, is only one-tenth of the weight of the load. More correctly, a tension of one-tenth the weight of the load would keep the cart from rolling backward ; a little more exertion on the part of the horse would be necessary to pull it up.

V.—The Screw.

The Screw is an application of the inclined plane. It is simply an inclined plane passing round a cylinder, as can be shewn by a very simple experiment. If a triangular piece of paper, such as *abf* in fig. 15, be wound round a pencil or ruler, the upper edge of the paper, which is evidently an inclined plane, will form a spiral exactly like a screw, except that a screw is formed by a spiral ridge. This spiral ridge is called the *thread* of the screw, and it works in a *nut* (M, fig. 16), which has a spiral groove to receive the thread, and is turned by means of a lever, L. When the screw is turned once round, it is carried forward in a fixed nut, or it draws forward a movable nut upon it, through the space between two of its threads. The resistance, therefore, has been pulled forward a distance, *eg* or *ga'* (fig. 15) ; but it has actually passed along the inclined plane *de*, supposing *de* to be the part that would go round the pencil. Therefore, the resistance overcome by the screw is to the force exerted in turning the screw as *de* is to *ec*. A screw, however, seldom acts by itself, being generally turned by a lever, so that, by means of the lever and the screw, a man is often able to overcome a resistance more than a hundred times greater than the force he applies to the lever.

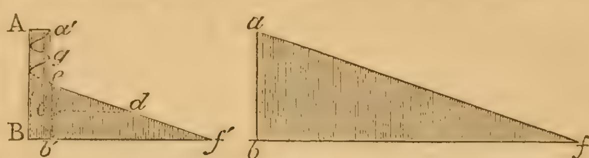


Fig. 15.

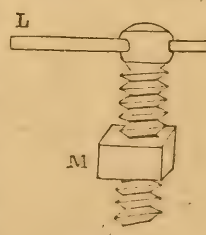


Fig. 16.

VI.—The Wedge.

The Wedge (fig. 17) is a contrivance for separating or overcoming resistances by being forced in between them, and is really a combination

of two inclined planes, the height of each being half the thickness of the back of the wedge. When a wedge is driven into a piece of wood up to the head, the wood at each side is forced back as far as half the thickness of the head. This has been done gradually by the sides of the split being forced up the inclined planes formed by the sides of the wedge. Now, as a certain force balances a greater resistance on an inclined plane the longer the plane is, it follows that the longer the wedge used the greater is the power gained by using it, whether in splitting an object, or in raising a weight.

Fig. 17.

Ships are raised in docks by driving wedges under the keel. Cutting and piercing instruments, as the plough, all act on the principle of the wedge. A familiar illustration of the principle is seen in the case of one glass tumbler placed within another, very little pressure on the uppermost one being sufficient to burst the lower.

HYDROSTATICS.

We have seen (Cohesion, p. 3) that all matter exists in one or other of the three states, solid, liquid, and gaseous. Liquids and gases have a general resemblance to each other in this respect, that their particles seem at liberty to glide about among one another without friction: they *flow*, and have hence received the common name of *fluids*, from Latin *fluo*, to flow. All liquids and gases have a certain degree of fluidity; but the property which chiefly distinguishes them is *elasticity*. A quantity of gas may be compressed into much less than its ordinary bulk, and when the pressure is removed it will return to its original volume; but no *ordinary* pressure produces any sensible compression on water or any other liquid. Liquids are thus practically incompressible, and therefore practically inelastic. The phenomena of liquids are of two kinds, corresponding to those of solids—the phenomena of liquids *at rest*, or in equilibrium, and the phenomena of liquids *in motion*. The department of Physics which treats of liquids *at rest* is called Hydrostatics, from Greek *hydor*, water, and *statikē*, at rest. A few of the facts or laws in connection with this subject are now to be considered.

1. The fundamental principle of hydrostatics is, that *when pressure is exerted on any part of the surface of a liquid, that pressure is transmitted to all parts of the liquid, and is exerted equally in all directions.* That it must be so is evident from the nature of a fluid, whose particles are perfectly movable among one another, so that any particle could never be at rest unless when equally pressed on all sides. The first inference from this is, that *the pressure of a liquid on any surface is*

proportional to the area of that surface. Suppose the box B to be filled with water, and to have a number of openings of the same size, as *a* and *b*, with pistons or plugs exactly fitting them; and, for greater simplicity, suppose the water to be without weight, so that we may consider merely pressure arising from the forcing down of the plug. If the piston at *a* be pressed in with a certain force—say, equal to a weight of one pound—this pressure will be transmitted to all parts of the vessel (because the particles of the liquid could not be at rest unless there was an equal pressure throughout), and thus to the piston at *b*. And since the piston is of the same size as that at *a*, the pressure on it is the same as the reaction of the water on the piston at *a;* in other words, there is a pressure of one pound on it. The pressure on the two, then, is two pounds, and both being equal in size, the area of the two is twice that of one of them. If there were a large piston, *c*—say, four times as large as *a*—the pressure on it would be four pounds. If a piston, one square inch in area, were pressed into a vessel full of water with a force of one pound, and if the area of one of the sides of the vessel were one foot, then the pressure of the water on that side would be 144 pounds.

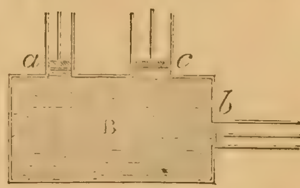


Fig. 18.

On this principle there has been constructed a very useful and powerful machine, named the Hydraulic Press, which is also called Bramah's Press, from the name of the inventor. The figure (19) shews the essential parts of the machine. H is a force-pump by which water is forced from the tank T, through the tube G, to F, the cavity of a strong cylinder, E. D is a piston which passes water-tight through the top of E, and is pressed upward by the pressure communicated to the water by the piston of the force-pump H. On the top of D is a plate, on which are placed the articles to be pressed, C; and the rising of the plate, caused by D being forced upward by the water, presses these against another plate, AA. It is very easy to calculate the pressure communicated to D; for, according to the law stated above, the pressure caused by the piston of H is to the pressure on D as the area of the piston is to the area of the end of D. If the area of the end of D were 1000 times greater than that of the piston of H, and the piston of H were pressed down with a force of 500 pounds,

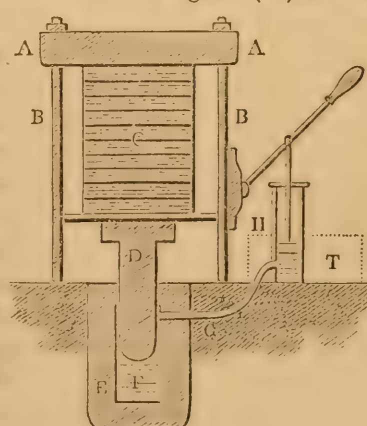


Fig. 19.

the pressure on D, and through D on the articles between the two plates of the press, would be 500,000 pounds, or above 200 tons.

The pressure caused by a piston being forced into a vessel filled with water, may also be caused by the weight of water itself; for whether the piston at *a* (fig. 18) be forced in with a pressure of one pound, or one pound-weight of water stand in the tube, the pressure in both cases is the same. In this way a very strong cask may be burst by a few ounces of water. In fig. 20, *a* is a cask filled with water, and *b* is a very narrow tube inserted in the top of the cask. If the tube hold only half a pound of water, and the bore of the tube be one-fortieth of a square inch, the pressure of the water in the tube will cause a pressure, transmitted by the water in the cask, of half a pound on every one-fortieth of an inch of the inner surface of the cask—that is, of nearly 3000 pounds on every square foot—a pressure which no ordinary cask could bear.

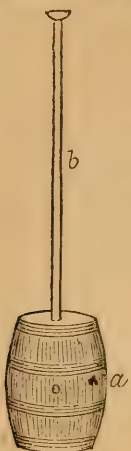


Fig. 20.

This bursting of the cask is an illustration, on a small scale, of the simple means by which the operations of nature are effected. For example, the water poured into a crevice in a rock by successive falls of rain will ultimately rise to such a height as to cause a pressure sufficient to burst asunder from the mass a large portion of the rock.

2. *In a liquid mass, there is a pressure increasing in intensity with the perpendicular depth.* The truth of this will be at once clear if we suppose a mass of liquid divided into thin horizontal layers. The upper layer must be supported on the second, and the pressure on the second layer is the weight of the first. And, since the second layer must be supported by the third, the pressure on the third layer is the weight of the two above it; and so on to any depth, the pressure at any depth always being the weight of the water above, so that it must always be proportional to the perpendicular depth. And this is the case whatever may be the shape or width of the vessel. Every one must have noticed with how much greater force water rushes from a deep vessel when the opening is near the bottom, than when it is near the top, or when the vessel is nearly empty: this difference is caused by the difference in the pressure of the water above.

3. *The free surface of a liquid mass in equilibrium is a perfect level.* Since the particles of a liquid are freely movable among one another, it follows that if the liquid were heaped up at any particular part it would always slide down again till the surface was level. There is a case, however, in which the fact is not perfectly clear at first sight—namely, when the vessel consists of different parts communicating with each other. A common tea-pot will afford a convenient illustration. The water stands

in the spout at the same height as in the pot itself; and it must do so, for if the water at B, for instance, were lower than at A, then the pressure under A would be greater than under B, since (§ 2) the pressure is proportional to the depth of the liquid; the water, therefore, could not be at rest, but a flow must take place into the spout, which would continue till the pressure in it was the same as in the pot, that is, till the water stood at the same level.

Fig. 21.

This principle is applied to the introduction of water into houses in towns. As fluids always rise to a level, no matter what distance the water may be conveyed by pipes, it will rise to the height of the source from which it is brought.

4. *A solid body, immersed in a liquid, experiences a pressure equal to the weight of the liquid which it displaces, and this pressure acts vertically upwards through the centre of gravity of the liquid displaced.* Let AB be a solid body immersed in water; it is evident that AB occupies the place of a quantity of water equal in volume to itself. Now, suppose AB not yet placed in the water, and AB, as seen in the figure, to be the water about to be displaced; this part of the liquid is supported by the pressure of the rest around. The pressure on the sides has no effect, because it is equal all round, and may therefore be disregarded: it is the pressure from below that properly supports the mass. And since this mass of water has a certain weight which acts at its centre of gravity g, the upward pressure keeping it in its place must be equal to that weight, and must act through its centre of gravity. Suppose, now, the solid to be substituted for the water, it must experience exactly the same pressure as acted on the water; that is, the solid AB is acted on by a pressure equal to the weight of the water it displaces, and acting vertically upward through the centre of gravity of the water displaced.

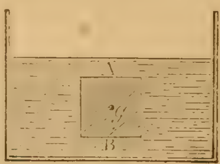


Fig. 22.

It is an obvious corollary from this, that *if a solid be weighed in a liquid, it will be lighter* (than its true weight) *by the weight of a quantity of the liquid equal in volume to the solid.*

This truth was first discovered by the ancient mathematician, Archimedes, and by means of it he was able to discover how much alloy the goldsmith, whom the king of Syracuse had commissioned to make a crown of pure gold, had fraudulently mixed with the metal. It is said that, one day when floating in his bath, it occurred to him that what was supporting his body was that which would support the water displaced by it; and he thought he could, by means of this principle, discover whether

the crown was of pure gold. He is reported to have been so overjoyed at the discovery, that he forgot to dress himself, and rushed through the streets, crying: 'I have found it! I have found it!' To test the crown, he first found the absolute weight of a piece of pure gold, and then its weight when immersed in water. He treated the crown in like manner, and found that it displaced more water in proportion to its weight than the piece of pure gold, which proved that the metal had been mixed with something lighter.

5. *A floating body displaces its own weight of the liquid.* We have seen that, when a body is immersed in water, a pressure equal to the weight of the water displaced acts upon it, pushing it upward, while its own weight tends to make it sink. If, then, these two pressures are equal, the body will rest in any part of the liquid; if the weight of the body is greater than the weight of an equal volume of water, the body will sink to the bottom; while, if the weight of a quantity of water, equal in volume to the body, is greater than the weight of the body, it will be forced upward to the surface. When this last takes place, the body is said to *float.* And, of course, part of it must rise above the surface, because, if it were to rest with its surface exactly level with the surface of the liquid, it might have rested at any part of the liquid; but it is supposed to have been forced upward to the surface. The question, then, comes to be, How much of the body will rise above the surface? or, which is the same thing, How much of it will be in the water? We have seen that a body, immersed in a liquid, remains *at rest* when the weight of a quantity of the liquid equal in volume to itself, is equal to its own weight; and from this it is clear that a floating body (as AB) will be at rest, when the weight of the water displaced by the submerged part B is exactly equal to the weight of the body. Thus the heaviest bodies can be made to float on a liquid, if only they can be so arranged as to displace a quantity of the liquid of weight greater than their own. A piece of iron sinks in water, but ships can be made of iron, because they are hollow, and displace a quantity of water of greater weight than their own.

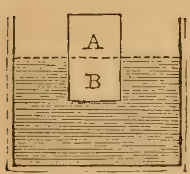


Fig. 23.

ACOUSTICS.

ACOUSTICS[1] is the science which treats of *sound*. Sound is the sensation produced when the vibrations of some sounding body are conveyed directly or indirectly to the organ of hearing. That a body producing sound is in a state of vibration at the time is seen in any stringed musical instrument, the prongs of a tuning-fork, the lip of a bell, &c. These vibrations must be communicated to the ear through some medium connecting the sounding body with the ear, the ordinary medium being the air. This is proved by the fact, that when a bell is struck in a chamber from which the air has been withdrawn, no sound is produced, and that the less dense the air becomes, the fainter are the sounds heard in it, so that on high mountains, where the air is very rare, what would elsewhere be loud talking is heard like whispers. Air, however, is not the only medium, the vibrations being conveyed through water, wood, and other substances. If the head be held under water, any noise at a distance, such as that caused by two stones being knocked against each other, is heard with great distinctness. Or if the ear be placed at one end of a log of wood, the slightest scratch at the other end is heard very distinctly, the vibrations being transmitted through the particles of the wood. Bodies denser than air are better conductors of sound, but, as air is the ordinary medium, the general principles of sound have reference to it. Vibrations are the wave-like motion which is communicated to the air by any shock, such as a shot, the blow of a hammer, or an explosion. The air is not made to change its place, but the compression of its particles caused by the shock is passed along like the undulations of a rope held at one end and moved up and down. These undulations pass outward from the body producing them, in all directions, exactly like those caused on the surface of water by a stone thrown into it, and, like them too, they diminish in force as they proceed outward.

Loudness of Sound.—The loudness of any sound depends upon the force of the concussion of the air, and the force with which this concussion is conveyed to the ear; so that, from the decreasing force of the sound-waves, in a certain ratio, the intensity or *loudness* of sound diminishes with the distance of the hearer from the object causing it. But a great many other things besides the distance have to be taken into account as affecting the intensity of sound. Thus, sounds at a distance are heard much better at one time than another: this arises from various causes. As was mentioned above, the denser the air is the better are sounds heard; a dense state of the atmosphere would therefore account for sounds being heard

[1] From Greek *akoustikos*, relating to hearing or sound, from *akouō*, to hear.

distinctly at a great distance at a particular time. Sounds are also better heard in a dry atmosphere, as moisture seems to interfere with the propagation of sound-waves. Although a simple current of air does not of itself produce sound (it only does so when it comes in contact with obstacles in its way, as trees, houses, &c., by which vibrations are produced), yet it will carry sound-waves in any direction; sounds are therefore heard more distinctly when there is a breeze blowing from the source of the sound towards the hearer.

Velocity of Sound.—The velocity with which sound-waves are propagated can be calculated very exactly, owing to the extreme rapidity with which light travels. The velocity of light is so great that for any distance within the limits to which sound could be heard, its passage may be considered as instantaneous. This being the case, the blow, shot, explosion, &c. causing any noise, may be *seen* to take place before the noise is heard; and the time that elapses between seeing the cause and hearing the noise is the time that it takes for the propagation of the sound-waves to the distance of the hearer. If a man be observed at a distance striking heavy blows on anything, the blow will be seen to descend some time before the sound of it is heard; so with the firing of a gun, the flash is seen before the report is heard. It has been found by experiment that sound travels at the rate of about 1142 feet per second, or of a mile in about four seconds and a half. The velocity is somewhat less, however, when the temperature is lower, being only 1090 feet at the freezing-point. In water, sound travels about four times, and in solids, from ten to twenty times more quickly than in air.

Reflection of Sound—Echo.—We are now to consider what takes place when a sound-wave meets a large obstacle to its progress. The vibration is to a small degree communicated to the solid, just as light is transmitted through a new medium; but the principal effect is to reflect the wave, just as a wave of the sea is thrown back from a rock. When a sound-wave is thrown back in this way from a flat surface, the sound is carried back to the point where it was produced, and this return-sound is called an *echo.* It may be produced by a perpendicular wall of rock, a wood, or other obstacle. If a sound be produced between two faces of rock, for instance, it will first be echoed by both; and then those echoed sounds (the sound being now doubled) will be thrown back from one to the other again and again, becoming fainter each time; so much so, that a shot in such a situation may be repeated forty or fifty times. The best echo is produced by a concave surface, such as the roof of a cave, by which the sound-wave is reflected to a *focus*, as in the case of rays of light. If one happen to stand so as to bring one's ear into the focus, the whole of the sound, concentrated at that point, falls upon the ear, and the effect is astounding.

The ears of animals are admirably adapted to receive impressions from the vibrations of the air caused by so-called sounding bodies. The external ear collects part of the sound-wave, and turns it into the passage which conducts it to the membrane from which the vibrations are conveyed to the auditory nerves. The *ear-trumpet*, which is a trumpet-shaped instrument, having a wide mouth at the end of a tube, is simply a contrivance by which a greater volume of the sound-wave is collected and conveyed into the ear.

Musical Notes.—We have hitherto spoken only of a single shock transmitted through the atmosphere as producing a single sound. The sensation conveyed to the ear when blows are struck with a hammer is a succession of distinct sounds. When sounds are produced in such quick succession that the successive pulses of the air cannot be distinguished by the ear, a musical *note* is produced. For example, if a toothed-wheel, with a plate of some thin elastic substance resting on the teeth, be turned slowly, the shock produced by the plate falling off each tooth is conveyed separately to the ear, and separate sounds are heard; but when it is turned more rapidly, the shocks all blend into one, and the sound heard is a continued 'whir;' and the more rapidly the wheel is turned the more sharp and shrill the 'whir' becomes. It is on this principle that notes are produced from the strings of musical instruments. When a string stretched between two objects is pulled aside in the middle, its elasticity causes it to return to its proper position; but the momentum it has meantime acquired carries it past to about the same distance on the other side. Its elasticity here comes into play again, and it is again carried past the middle straight position almost as far as it was pulled aside at first: the same thing is repeated; and this goes on, the vibrations on each side gradually becoming less and less, till the string at last comes to rest. When this is done with a slack string, the vibrations are slow; but when the string is tight, the vibrations are so quick that, as in the case of the toothed-wheel when turned rapidly, the separate pulses are blended into a continuous note; and the tighter the string is pulled, the sharper is the sound produced by its vibrations. A good illustration of successive vibrations blending to cause a continuous sound, is the 'buzz' of a fly, which is supposed to be not the voice of the insect, but the sound produced by the rapid vibrations of its wings. It is on this rapidity of vibration that the difference of sounds depends. We observed that the 'whir' of a toothed-wheel striking an elastic plate becomes more shrill the quicker the wheel is turned, and that the sound produced by a vibrating string is sharper the quicker the vibrations are made. Now, a short string will evidently vibrate more quickly than a long one; therefore, every degree of sharpness of sound can be produced from strings by making them of different lengths and of

different tightness. A string half the length of another, and of the same tension, vibrates twice as quickly, and the musical note produced by it has a fixed relation to that produced by the other. From this it will be understood why a fiddler places his fingers up and down on the strings as he plays. The string can only vibrate as far as the point on which he places his finger; by putting his finger on the string a good way up, he shortens the string, and a sharper sound is produced; thus, besides having the range of the four strings, which give different notes from being stretched to a different tightness (the bass-string being also loaded with copper wire, to make it vibrate more slowly), he has a range of notes on each string, by means of shortening them to different lengths.

Different notes are also obtained from pipes, according to their length. The sound produced by a pipe is due to the vibrations of the air in the pipe, which are caused by the shock communicated by blowing into it, or partly by the construction of a mouth-piece. The shorter the pipe, the greater is the shrillness of the note produced. Every one knows that the note of a large flute is soft and mellow, while that of a small one is shrill. In an organ, there is a pipe for every note, the different lengths being calculated with extreme care; while in a flute a similar effect is produced by opening and shutting holes along the length of the one pipe. Another system on which musical notes are produced is by placing a slender elastic plate over a slit or opening through which air is made to pass, by blowing, as in the musical toy of this description. The air causes the little pieces of steel to vibrate with great rapidity and thus produce a musical note. The human voice consists simply of musical notes produced by the vibration of two membranes at the top of the windpipe, with their free edges opposite each other, and a slit or opening left between them for the passage of the air by which they are vibrated. When a boy places a blade of grass between his thumbs, and, by blowing on the edge, produces a note by no means musical in one sense, the note is produced exactly on the principle of the human voice as produced by the larynx, being caused by the extremely rapid vibrations of the edge of the blade of grass. The voices of children and women are shriller than those of men, because the membranes of the larynx are shorter in the former than in the latter, and thus produce sharper notes.

OPTICS.

The subjects treated of in the science of OPTICS[1] are Light and Vision. We learned in the chapter on ACOUSTICS, that the sensations of Sound are produced by vibrations in sounding bodies being communicated to the air, and by it transmitted to the nerves of the ears. It is now believed that both Light and Heat consist of a vibratory motion of the particles of light-giving and hot bodies, and that they are transmitted in a manner exactly similar to the transmission of sound. The medium, however, cannot be the air, since light and heat pass where there is no air ; philosophers have accordingly come to the conclusion that all space is occupied by an infinitely elastic substance or fluid called *ether*. The vibrations of the particles of a luminous body are communicated to the ether ; the pulses transmitted through it enter the eye, and strike upon the retina, and, being thence conveyed to the brain, produce the sensation of Sight. These vibrations pass from a luminous body in every direction, and for this reason Light is said to be composed of *rays*, from Latin *radius*, the spoke of a wheel, and these rays are said to be *divergent*. Light travels at the rate of about 194,000 miles in a second.

When light falls on the surfaces of bodies, some or all of the rays are *reflected*, or thrown back by the surface ; or, some or all of the rays are *transmitted*, or pass through the body, according to the nature of the body, and the manner in which the light falls upon it. Rays which are transmitted from one substance into another, are bent out of the straight line, and are said to be *refracted*. The following lessons on Optics consist of a short statement of the Laws of Reflection and Refraction.

Reflection.

Let AB (fig. 24) be a reflecting surface, as a mirror, with a ray of light falling on it in the direction of *ed*; and let *cd* be a line perpendicular to AB : then, by the first law of reflection, the ray *ed*, will be reflected from AB in the direction *db*, so that *ed*, *dc*, and *db* shall all be in the same plane ; and by the second, the angle *cdb* is equal to the angle *cde*. A ray *falling on* a surface, as *ed*, is called the *incident*[2] ray, and *d* is called the point of *incidence; cd*, the perpendicular at the point of incidence, is called the *normal;* and *db*, the *reflected* ray. The first law of reflection may

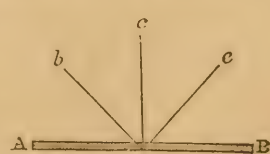


Fig. 24.

[1] From Greek *optikos*, relating to sight.

[2] From Latin *incido*, to fall upon.

now be stated thus—*The incident ray, the normal, and the reflected ray are all in one plane.* Again, *edc* is called the angle of incidence, and *cdb* the angle of reflection; and the second law of reflection is—*The angle of reflection is equal to the angle of incidence.* Two other facts will now be easily understood.

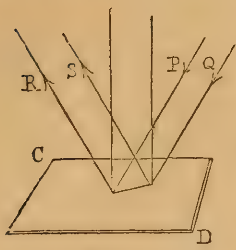


Fig. 25.

1. Rays of light that fall on a reflecting surface parallel to each, will be reflected parallel to each other. Rays being reflected from a surface *at the same angle* as they fall upon it, it is evident that after reflection they must remain parallel. If P and Q (fig. 25) are parallel when they fall on CD, R and S will also be parallel.

2. When *divergent*[1] rays, or rays that spread out from a point, fall on a mirror, the point from which the reflected rays *seem to proceed*, is on the opposite side of the mirror, and at a distance equal to the distance of the point from which the rays actually proceed. Thus, let rays, diverging from the point Q (fig. 26), fall on a mirror at A and B, and be reflected in the direction of R and S; the point *q*, from which they seem to proceed, is on the opposite side of the mirror, and the distance N*q* is equal to the distance NQ.

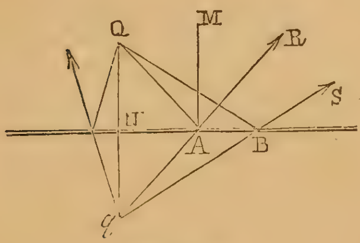


Fig. 26.

Refraction.

The body or substance through which light passes is called a *medium.* When light passes from one medium into another, it is *refracted* or bent out of its straight course. This is seen by a very simple experiment. Let a coin be placed in the bottom of a basin so that it is just out of sight. If water be poured into the basin without moving the coin, it will gradually come into sight, the cause being, that the light from the coin is bent out of the straight line in passing from the water into the air, so that the light that comes from *a*, along *a*DC, seems to come straight from *b*, and the coin seems to be raised up.

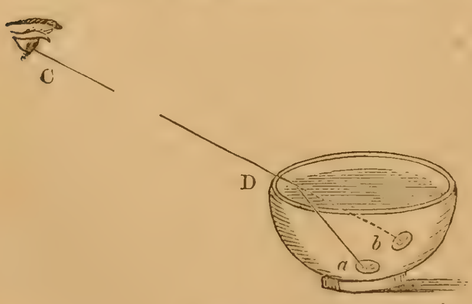


Fig. 27.

[1] From Latin *dis*, asunder, and *vergo*, to incline.

Another example of the same thing is the bent appearance of a stick when held partly in water, the explanation being, that the light from every part of the stick under water is refracted, so that it seems to be raised up, as was the case with the coin. So, too, objects at the bottom of a clear stream or pond appear to be raised up, and the water seems less deep than it really is. The principle on which these phenomena take place is, that light when passing from a *rarer* to a *denser* medium (for example, water and glass are *denser* than air, and air is said to be *rarer* than water or glass) is refracted *towards* the perpendicular; and on passing from a denser into a rarer, is refracted *from* the perpendicular; and this in proportion to the relative velocity with which light passes through the different media. Thus, suppose a ray of light to pass through a piece of glass: on entering the glass, it is turned towards the perpendicular to a certain extent; but on leaving the glass and entering the air again, it will be refracted from the perpendicular; and as this must be exactly to the same extent as it was turned towards it on entering the glass, it is clear that the ray, on emerging from the glass, will proceed in the same direction as it was doing before it entered.

Having hitherto treated of media with parallel surfaces, we will now consider the case of a medium the surfaces of which are not parallel but are supposed to meet. A medium of this form is called a *prism*, as BAC, and the angle at which the surfaces meet, as A, is called the *vertex*.[1] A ray of light transmitted through a prism, of any substance denser than the surrounding medium, is always refracted *from the vertex*. Let a ray, SP, fall on the transparent prism BAC at P; let *nn′* and *mn′* be the perpendiculars to the two surfaces. On first entering the new medium, the ray will be refracted from its straight course, SD, towards the perpendicular, into the direction of PQ, say. Now, at first sight, it might be expected that, on emerging into the air again, it would proceed in a direction nearly the same as before entering the prism, that is, turn towards the vertex of the prism; but it is clear, from the construction of the figure, that the ray must emerge on the opposite side, that is, turn away from the vertex along QR. It would be the same, although the incident ray were on the side of the perpendicular next to the vertex; because the refracted ray *in the prism* must always be on the side of the perpendicular next the vertex, and must therefore always emerge on the opposite side, away from the vertex.

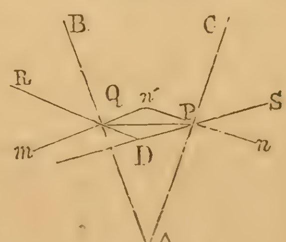


Fig. 28.

All the effects produced on light by passing through different lenses

[1] Latin *vertex*, the top or *turning* point, from *verto*, to turn.

will now be easily understood, especially if the general principle with

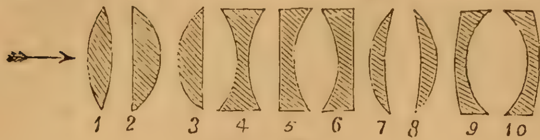


Fig. 29.

regard to prisms be kept in mind, that rays of light transmitted through them are always refracted towards the thick part, because most lenses are simply *double prisms.* Thus, take the double-convex and the double-concave lenses—1 and 4 in the figure: the first is as if two prisms were fixed together with their vertices turned outward, and the second the same, only with the vertices of the prisms meeting in the middle. When a ray of light, as RI, fig. 30, falls on a convex surface, as AVB, the perpendicular (or *normal*) at that point, NIC, is the perpendicular to the tangent-plane; and the ray being refracted towards the

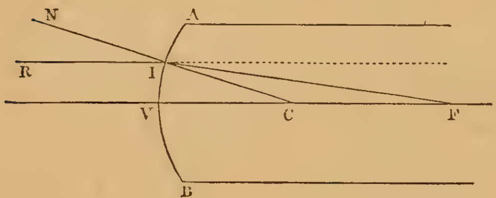


Fig. 30.

perpendicular, as IF, is therefore turned towards C, the centre of the curve of the surface. Now, if a ray fall on any other point of AV, since the normal must always be the line from that point to C, and the ray must be refracted towards the normal, it must also be turned towards C; and so for all rays that fall on AV. In the same manner, all rays that fall on VB would be turned towards C, because they must all be refracted towards the normal at every point, and the normal must always point to C. The effect of the whole surface, AB, then, is to draw rays of light that fall on it together, to a point behind the surface. Rays which draw together in this way are said to *converge.* This is the effect produced by rays of light which fall on the transparent *cornea* of the eye; they are made to converge and pass through the pupil; at least, by means of it, more rays pass through it than if there had been no refracting medium in front of the

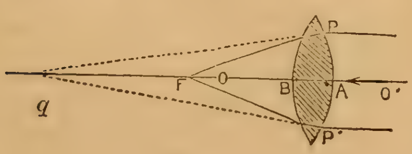


Fig. 31.

iris. (HUMAN PHYSIOLOGY, page 73.) This being the effect of one convex surface, it is very much greater when there are two together, as in a double-convex lens, fig. 31, which will be at once clear from what was said of the prism. The effect of the prism was seen to be to cause a double refraction towards the thick side; now, one side of a double-convex lens, as PAB, is equivalent to a number of prisms all turned one way, because at every point of the curved

surface we might suppose the plane face of a prism. Also the other half, as P′AB, is equivalent to a number of prisms all turned the other way; so that the whole effect of a double-convex lens, as PP′, is to cause a double refraction of all rays that are transmitted through it *inwards*. Thus, suppose a number of parallel rays to fall on the lens PP′; let one fall at P; then at the first surface it is refracted into the direction Pq, and if not further interfered with, it would meet the axis at q (corresponding to F in fig. 30), but at the second surface it is again refracted, and thrown more towards the thick part of the lens, so that it meets the axis at F. Again, of those that fall on the other side, let one fall at P′; it is refracted at the first surface into the direction P′q, and then at the second it is also turned to F. This is what takes place in the eye, when the light that enters by the pupil is transmitted through the *crystalline lens*. (HUMAN PHYSIOLOGY, page 74.) The point, F, at which the rays of light meet the axis or middle line O′q (for they all meet it at one point), is called the *focus*. In the eye this focus falls on the retina, and the cause of defective eyesight is simply that the rays of light are brought to a focus, not on the retina, but either in front of or behind it. In the former case, the individual is said to be *short*-sighted or *near*-sighted, and in the latter, *far*-sighted. The principle on which spectacles help to remedy those defects will be explained presently. After what has been said of a convex surface and the convex lens, it needs no proof to shew that the effect of a concave surface and of a double-concave lens (fig. 29) is exactly the reverse. As the normals to a concave surface all meet in the centre of the curve *outside* the body, inside they all *diverge;* and therefore parallel rays of light transmitted through a medium with a concave surface meeting them, being all refracted towards the normals, must all be made to diverge also. Then as to a double-concave lens, if we suppose it to be the same as two prisms with their thick part outwards, it is at once clear that all rays transmitted through it must suffer a double refraction outwards, that is, be made to diverge.

A very few words will now make the principle of spectacles perfectly intelligible. In the case of a near-sighted person, the defect in his sight is that rays of light are brought to a focus *in front of* the retina, the cornea and crystalline lens making the rays converge too much. To remedy this, it is necessary to make the rays *diverge* a little before entering the eye. This we saw to be done by a double-concave lens; therefore, near-sighted persons often wear spectacles with double-concave lenses. The defect in the case of far-sighted persons is that light is brought to a focus *behind* the retina: the refracting power of the cornea and crystalline lens is not strong enough, and it is necessary to make the rays converge. This, as we saw, is the effect of a convex lens; therefore, far-sighted people wear spectacles with double-convex lenses.

ELECTRICITY.

Electricity received its name from the Greek word *ēlektron*, amber, in which substance it was first detected. It was found, from the earliest times, that when a piece of amber was rubbed with a dry cloth, it had the power of attracting small light bodies lying near it. In later times, it was observed by scientific men that sulphur, glass, sealing-wax, and many other substances had the same property; and now-a-days electric experiments are all made with these common substances, instead of the comparatively rare and costly amber, especially since they exhibit the phenomena of electricity in as great perfection as the substance in which it was first discovered.

In order to observe better what takes place, let us suspend something very light—a little ball of pith of the elder-tree is generally used—by a silk thread from a glass tube, as in the figure (the reason why glass and silk are used will be explained afterwards). If a glass tube be rubbed with a piece of dry silk, and then held near the pith-ball, the latter will at first be drawn to the glass, and then be driven away, as indicated in the figure. If a stick of sealing-wax be taken next, rubbed with a piece of flannel, and held to the ball, which has just been repelled by the glass, the same thing will take place—the ball will first be attracted, and then repelled. If the glass be rubbed again, the same thing may be repeated of course; so with the wax; and the pith-ball might thus be kept playing between the two for any length of time. There are thus two kinds of electricity, one produced in glass when rubbed with a piece of silk; and the other in sealing-wax when rubbed with a woollen cloth. When the electrified glass attracts the pith-ball, electricity is communicated to the ball, and then it is repelled; in other words, two bodies charged with the same kind of electricity repel each other. Then the ball is attracted by the wax, and is only repelled again when the electricity received from the glass has been replaced by the kind produced in the wax; and we infer from this that two bodies charged with the different kinds of electricity attract each other. Special names have been given to these two kinds of electricity: the kind produced in glass and a number of other substances is called *vitreous*, from Latin *vitrum*, glass; while that produced in sealing-wax and a number of other substances of a resinous nature is called *resinous*.

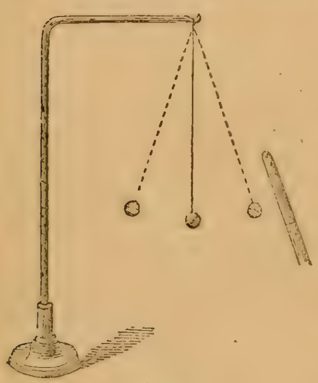


Fig. 32.

Instead of these two names, however, *positive* and *negative* are now more frequently used ; and for convenience, the algebraic signs corresponding to these are employed, + and −. The sum of what has been said may now be stated thus: *Bodies charged with either positive or negative electricity attract bodies charged with negative and positive electricity respectively, and attract bodies not electrified at all; but they repel all bodies charged with electricity of the same kind as their own; further, electricity can be communicated by contact from one body to another.*

In the above experiment, a particular substance is rubbed with a particular kind of cloth, the glass with silk, and the sealing-wax with a woollen cloth. When electricity is produced in a substance by friction, electricity of the opposite kind is produced in the rubber or substance (a cloth generally) with which it is rubbed ; and a body, which becomes charged with positive electricity when rubbed with one substance, may become charged with negative when rubbed with another. Thus, when glass is rubbed with silk, the electricity of the former is positive, and that of the latter, negative ; but if the glass be rubbed with a cat's fur instead of silk, the electricity of the former is negative, and that of the latter, positive. In the following list, each body, when rubbed with the one before it in order, becomes charged with negative electricity ; when with the one coming after it, with positive—cat's fur, glass, linen, feathers, wood, paper, silk, shell-lac, ground glass.

It must be remembered that all bodies do not become charged with electricity when rubbed ; those that do are called *electrics*, and those that do not, *non-electrics*. There is another distinction to be noticed in bodies, and that is with regard to receiving the electricity which has been produced in an electric ; those that do are called *conductors*, and those that do not, *non-conductors*. Most bodies are electrics, but it makes a material difference in this respect whether the body be a conductor or not ; because, if the electric be also a conductor, the electricity produced is immediately carried off ; while, if it be a non-conductor, the electricity remains on the surface, and is more apparent. Thus it happens that practically the most powerful electrics are non-conductors. The most important class of conductors are the metals. Water is also a good conductor. A few of the principal non-conductors, and thus, in a certain sense, the best electrics, are shell-lac, caoutchouc, amber, resin, sulphur, wax, glass, gems, silk, wool, hair, dry paper, leather, camphor, chalk, lime.

We can now explain why the pith-ball, made use of in the experiment, was suspended by a *silk* thread from a *glass* stand. Glass and silk are non-conductors, and so the electricity communicated to the pith-ball could not be conveyed away by these substances, as it would have been if it had been attached to a conductor ; as, for instance, if it had been fastened by a

wire to an iron stand. A conductor cut off from communication with the ground by being fixed on non-conductors, in this way, is said to be *insulated.*

Let us now return to our first experiment. We saw by it that positive electricity attracted negative, and negative, positive; and also that *both attracted bodies not electrified at all:* it will now be shewn that the last part of this statement is the same as the first. If a brass cylinder be fixed on a glass stand, with a pair of pith-balls suspended by a cotton thread (not silk this time, because it is not desired to insulate them from the cylinder) at either end, and placed near another insulated conductor charged with positive electricity, this is what will happen—the balls will be repelled from each other, as in the figure, shewing that each pair has become charged with the same kind of electricity. But it is found that the electricity at the two ends is of different kinds, that in the end next the ball being negative, while that in the other end is positive. This is quite in accordance with the result of our first experiment, that positive electricity attracts negative, and repels positive, and *vice versâ.* From this it is manifest, that in all conductors there exist (without friction) the two kinds of electricity, and that these are acted upon by an electrified conductor exactly in the same way as if the electricity had been produced by friction in both. It will now be seen that, when the rubbed glass attracts the pith-ball the first time, the attraction is not different from the subsequent attractions; the positive electricity in the glass repels the positive in the ball to the opposite side, and attracts the negative. This attraction is great enough to overcome the slight weight of the ball; when contact takes place, the negative electricity in the side of the ball next the glass is replaced by positive electricity from the glass. The ball is then charged altogether with positive electricity, and of course is now repelled by the glass; but at the other side, the sealing-wax which is charged with negative electricity attracts it; and so on. The influence which an electrified conductor thus exercises on a non-electrified one is called *Induction.*

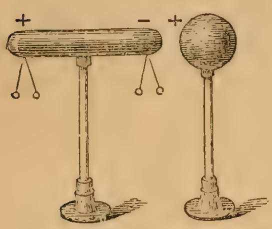


Fig. 33.

Lightning.

In the case of the pith-ball, when induction takes place, owing to its lightness and the manner in which it is suspended, it comes in contact with the glass, and electricity thus passes to it from the glass; but if, in fig. 33, there were a sufficient quantity of electricity in the ball, and the attraction were great enough, it would pass to the cylinder without contact; and there would be a slight flash of fire and a slight crack. Now, this flash

and this crack are lightning and thunder in miniature, for the black thunder-clouds that we see in a thunder-storm are clouds charged with electricity. When two thunder-clouds approach each other, induction takes place, and owing to the immense quantity of electricity the two contain, when it passes from the one to the other, the flash is of exceeding brightness, and the report deafening. Sometimes the induction takes place between a cloud and a prominent object on the ground, such as a steeple, a tall chimney, a tree, or an animal. Anything will do, if it form a point near enough the cloud to cause the electricity to overcome the resistance of the intermediate space; and the consequences are generally fatal to the object in this position. But it is not necessarily so; the destructive effects of lightning, or of electricity rather, only take place when it meets with resistance—that is, when induction takes place between a thunder-cloud and some object which is a bad conductor of electricity. Hence the object of lightning-conductors. Metals being good conductors, if a rod of metal have its point extending beyond the top of any prominent object, and pass down into the ground, when a thunder-cloud happens to be near, and induction takes place, the electricity, which would otherwise have shivered the non-conducting steeple or chimney, passes harmlessly down the metal rod.

It may now be asked where this vast quantity of electricity in the thunder-cloud comes from. We saw that electricity is produced by friction; this, in the case of the thunder-cloud, is one source of it, for there are many different kinds of friction going on in nature. The friction produced by the wind in various ways is very great; thus electricity may be produced in a piece of glass by a blast of air from a bellows, instead of by rubbing. But, besides friction and all other forms of mechanical action, electricity is produced by all kinds of physical and chemical action; it is produced by the great system of evaporation which is continually going on from all bodies of water, and also from the processes of vegetation in which water is being continually separated and evaporated from plants, so that the vapours and gases that rise into the air are all more or less charged with electricity; and this electricity, which is generally diffused through the atmosphere, becomes occasionally concentrated in clouds, and is then liberated in the form of lightning.

The Electric Telegraph.

In the form of lightning, electricity is often very destructive, and is at all times very terrible; but the reason and skill of man have enabled him to turn it to account in a most useful manner. By means of the electric telegraph, a message can now be sent half round the world in a few hours.

We have said that one of the sources of electricity is chemical action;

electricity produced in this way is called Galvanism,[1] or Voltaic[2] Electricity. When two plates, one of copper, and the other of zinc rubbed over with mercury, are placed in contact in a vessel of water in which is a little sulphuric acid, bubbles of gas are formed; and when the plates are removed, the zinc one is found to have lost in weight, the part it has lost being dissolved in the water. The same action takes place, although the plates are not in contact, if they are joined by a copper wire, as in the figure. In consequence of this chemical action, it is found that a current of electricity passes along the wire from the copper plate, in which positive electricity is produced, to the zinc, in which negative is produced. Further, under the liquid, a current passes from the zinc plate to the copper; so that by means of the wire and the liquid, the electricity makes a complete circuit; and such an arrangement receives the name of a galvanic or voltaic *circuit.* By employing a number of plates, the zinc ones being connected with the copper ones in a series, the strength of the current is of course increased, and such an arrangement is called a *galvanic battery.*

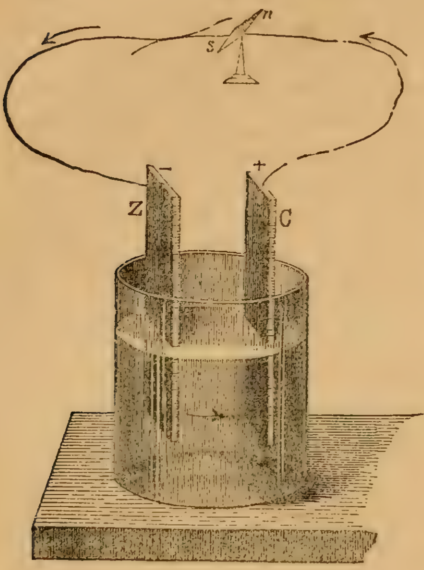


Fig. 34.

For the proper understanding of what is to follow, it will be necessary to give here a short description of magnets. There is a certain ore of iron which has the power of attracting iron. It was first found in Magnesia or Lydia, in Asia Minor; hence a piece of this ore was called a *Magnet*, or Lydian-stone, which last name (probably from the power of the ore to *lead* or attract things) became changed into *loadstone.* When a small magnetic bar is nicely balanced on a fine point, it is called a magnetic needle, and has the remarkable property of always pointing north and south, being of course free to move.[3] Such a piece of ore is called a natural magnet. An artificial magnet can be

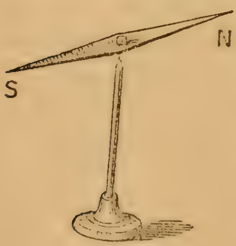


Fig. 35.

[1] So called from *Galvani* of Bologna, its discoverer.

[2] Voltaic Electricity, or Voltaism, so called from *Volta*, an Italian.

[3] The mariner's compass consists simply of a needle of this kind, balanced in the centre of a circular box, on the edge of which are letters for the different *points*, N., S., E., W., &c.

made by rubbing a piece of iron with a natural magnet; but the strongest magnets are got by coiling the wire of a galvanic battery round a piece of iron. While the electric current is passing through the wire, the iron becomes strongly magnetic, and ceases to be so as soon as the current is stopped. Magnets are of different forms. Perhaps the most common form is that of the horse-shoe magnet (fig. 36), the object being to bring together the two ends, called the poles, N and S, in which the strength of the magnet is concentrated. The part *sn* is not properly a portion of the magnet, but is a piece of iron, called an *armature*,[1] used partly for convenience, but chiefly for keeping in the magnetism. Fig. 37 shews an electro-magnet, which is a piece of iron that can be rendered magnetic by an electric current, as described above. Neither the horse-shoe nor the armature is magnetic in itself, and therefore they will not remain in

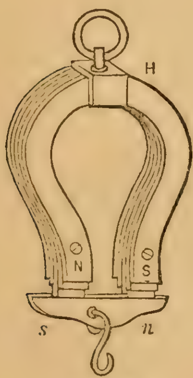


Fig. 36.

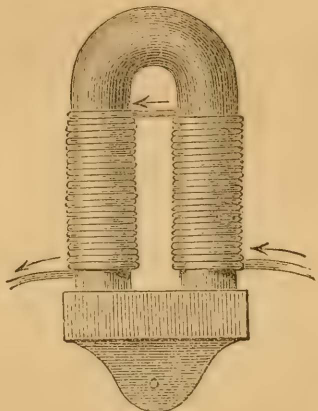


Fig. 37.

contact; but as soon as the electric current is sent through the wire coiled round the magnet, the armature is pulled to it with a sharp click. We now proceed to describe the working of the Electric Telegraph.

There is one kind of telegraph which depends on the effect that an electric current has on a magnetic needle placed near it, as in fig. 34, of turning it out of its natural position, in which it points north and south; but as we can only describe one, it will be one on another principle, which is perhaps the best and the one now most extensively adopted, namely, the electro-magnetic. Of this, again, there are various modifications; the instrument here described is Morse's.

We have seen that an electro-magnet is only magnetised when the current is passing, and this can only be when the circuit is complete, as in fig. 34, by the wire and the liquid. Now, everybody knows how the wire of the telegraph passes from one station to another; but how about the

[1] From Latin *armatura*, armour, protection.

other part of the circuit—the part played by the liquid in fig. 34? In the case of the telegraph, the *earth* is substituted for the liquid, for if the wire which goes along the lines be attached to the copper plate of the battery, and a wire, attached to the zinc, be carried down into the earth, the circuit is complete. In fig. 38, then, L is the line-wire, and E the earth-wire, both of which are made continuous with the coils of wire on the electro-magnet, MM′; the armature, A, is attached to a lever, *ll′*, which turns on the axis *k*. Whenever the current is made to pass through the wire, the armature is drawn down, bringing the end of the lever with it; this raises the other end, to which is fixed a sharp point, *p*; opposite this point is a

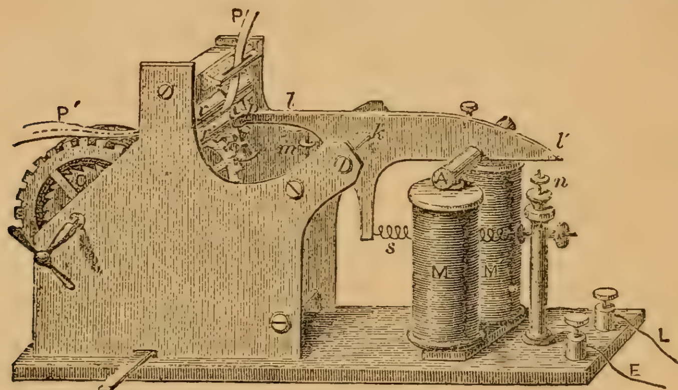


Fig. 38.

groove in the roller, *r*, and over this groove is made to pass a slip of paper, PP′, which is made to move towards P′ by the rollers, *rr′*. These rollers are worked by clock-work, independently of the rest of the machine. When the point *p* is raised into the groove on the roller *r*, a raised mark is made on the upper surface of the paper, which will be a dot or a line according to the time the point is raised, that is, according to the time the circuit is kept complete; as soon as the current ceases, the armature is left by the magnet free to rise, and the end of the lever, with the point, is pulled down by the spring *s*. By means of the dots and lines thus made on the paper, an alphabet is constructed, and words can thus be written down at the distance of thousands of miles.

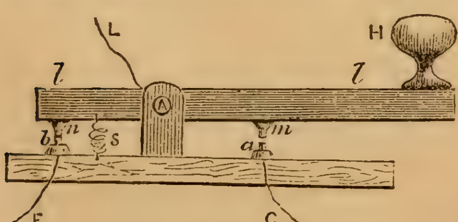


Fig. 39.

But now, how is this system of stopping and setting agoing of the current managed at the station from which the message is sent? It is done by what is called a key, fig. 39. This is a lever, *ll*, which moves on an axis, A, and is worked by

a handle, H. To the key are attached three wires: the line-wire, L; a wire, E, attached to a Morse's Recorder, at its own station; and one, C, attached to the copper plate of a galvanic battery. The ordinary position of the key is as seen in the figure, the nipple *n*, in contact with the little anvil *b*, that end of the lever being held down by the spring, *s*; so that, when a message is to be received, the current passes from L, by A, *l*, *n*, *b*, and E, to the recorder. But when a message is to be sent to another station, the handle, H, is pressed down, the contact between *n* and *b* is broken, and the nipple *m*, is now brought down on the anvil *a*. This connects the copper plate of the battery with the line-wire to the distant station; and the current passes from the copper plate through the line-wire, through the key at the distant station (which is in the position seen in fig. 39), and through the coils of the electro-magnet of the recorder. From the recorder it passes down the earth-wire, and then back, through the earth, to the zinc plate of the battery. The time during which the sharp point in the recorder is to press upon the paper, as before described, is thus regulated by means of the handle, H.

HEAT.

1. **Development of Heat.**—HEAT may be produced by mechanical means in three ways, by friction or the resistance of the surfaces of two bodies when rubbed, by percussion or the striking of one body against another, and by compression.

(1) *By Friction.*—If a smooth metal button be stuck on a cork, and rubbed on a piece of soft deal-wood, as a form, it will become heated by the friction; and if rubbed long enough, will become so hot as to scorch wood and paper, and set fire to a match. Considerable exertion of the arm, however, is required to produce the latter result. This experiment affords an illustration of a general principle in nature, that all energy expended results either in *a certain amount of work done or of heat produced.* Accordingly, energy must be so directed as to produce the exact result desired. If we wish to produce heat, as in the case of the button, or in warming one's hands, the more energy that is applied to overcome the friction, the greater is the amount of heat produced. If sufficient energy be expended, the heat becomes so great that the rubbed bodies take fire. Savages, for example, light their fires by rubbing two sticks together; forests have been set on fire by the friction of two branches waving in the wind; and destructive fires have been occasioned by friction in a piece of machinery. More generally, however, energy is directed to the performance of work, and in this case all that goes to produce heat is lost. If, when a man is

sawing wood, the blade of the saw be held by the wood, the force required to overcome this friction, although it has the effect of heating the saw, is lost, because the object is not to heat the saw, but to cut the wood. To prevent this friction, the teeth of the saw are set outward to each side alternately, so as to make an opening wide enough to allow the blade to work freely; and sometimes a piece of wood is inserted in the cut, to keep the sides apart. When the friction cannot be altogether prevented, it is eased by rubbing the saw with grease. For the same reason, the axles of wheels of carts, railway carriages, and other machines, are kept carefully greased.

(2) *By Percussion.*—On picking up a lead bullet, or rather the flattened fragment of one, just after it has struck a metal target, it is felt to be hot. The heat of the flattened ball is the exact equivalent of the force with which the bullet was moving when it struck the target, together with that communicated to the spot struck. Again, when a piece of cold iron is hammered, it becomes hot—that is, the energy expended in the blows is converted into heat in the iron, just as happens when a button is rubbed.

(3) *By Compression.*—When the density of a body is increased by compression, heat is developed according as the volume of the body becomes diminished. When books are squeezed between the plates of a hydraulic press (see fig. 19, page 17), they are found to be heated; in other words, the force applied to the press has been converted into heat. Similarly, heat is evolved when a weight is laid on a metal pillar.

From a consideration of the foregoing and many similar facts, the conclusion has been arrived at, that *heat is a form of motion.* Thus, the heat produced by a bullet striking a target is simply the motion, which the bullet had before it struck the target, transferred to the atoms of the lead as well as to those of the metal struck; and the heat of the hammered iron is simply the motion of the hammer transferred to the atoms of the iron; and similarly in any case of friction or compression.

2. **Change of Condition.**—It must be distinctly understood that *all* bodies have a greater or less amount of heat. We are obliged to conceive of a point at which there is an entire absence of heat, but of that point we have no experience, and beyond it the heat of bodies differs merely in degree. The temperature of the human body is about 90°, and we are accustomed to speak of bodies with a lower temperature than this as cold, and of all having a higher temperature as warm or hot. Taking for granted, then, that heat is motion among the atoms of the body, let us consider how different bodies are affected by it. In all bodies, the atoms vibrate backward and forward, and these vibrations have greater or less velocity and extent, according to the amount of heat in the body. The result of these vibrations is that the atoms repel each other, so as to make the body composed of them, when heated to more than its ordinary temperature, occupy a larger space. Iron, for example, expands when heated, as was

noticed under Density (page 5). There is thus a contest going on between the binding power of cohesion and the repelling power of heat. At first, with a small amount of heat, the cohesion holds its own; but as the heat increases, the vibrations become more violent, and the atoms are strongly pushed apart. Cohesion, then, has less power, because it has to act at a greater distance; therefore, as the repulsion of the heat increases, the attraction of cohesion diminishes, till the atoms gain sufficient freedom to be able to slide or roll upon one another. The body is then said to be *in a liquid state.*

In the liquid state, the power of cohesion has not been altogether conquered; the atoms, although they are movable on one another, still resist being torn asunder. But if the heat be still further increased, the last feeble efforts of cohesion are overcome, and the atoms fly apart in the form of *vapour.* When a liquid has assumed the gaseous form, it is clear that the space it occupies is very much increased; thus, water converted into steam occupies a space about 1700 times greater than it did before—that is, a cubic inch of water becomes a cubic foot of steam.

3. **Vaporisation.**—When sufficient heat has been applied to a liquid to make it assume the form of visible vapour, the first particles fly off from the surface, as is seen in the vapour that rises from all water when it becomes heated at all. Let us see what is going on meantime within the liquid mass. At the bottom of the liquid, where the heat is generally applied, the particles are being more and more repelled from one another, the liquid becomes lighter than that above it, and rises, while the liquid above it sinks down, as seen in the figure, which represents a vessel of water with a lamp under it. While this is going on, small bubbles of vapour rise from the bottom; but as they rise near the surface, where the temperature is lower, they are condensed again to water. The formation and condensation of these first bubbles give rise to the *singing* sound heard coming from water just before it boils. When, however, the whole of the water has been raised to a certain temperature, the bubbles of vapour that are formed at the bottom rise to the surface, and the water is then said *to boil.* Sometimes the bubbles are seen to rest on the surface; that is, there is a small quantity of vapour enclosed in a thin coating of the liquid. The repelling power of the heat in the steam of course tends to make it burst the bubble; but it is prevented for a short time from doing so by the pressure

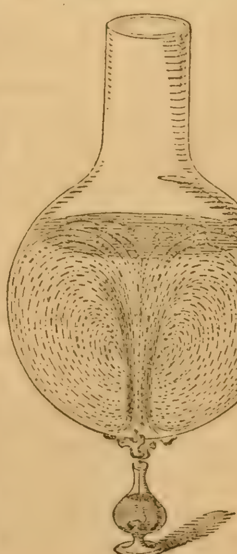


Fig. 40.

of the air, which amounts to 15 pounds on every square inch. But take a bubble when it is first formed at the bottom of the water; there the pressure on it from without is the weight of all the water above it, as well as that of the air; so that the heat necessary to raise a quantity of water to the *boiling-point* is exactly the quantity of heat that will introduce among its particles a force of repulsion sufficient to overcome the pressure arising from the weight of the liquid above it and the weight of the atmosphere. Hence, to boil a large quantity of water, its temperature must be higher than in a smaller quantity, because the pressure to be overcome by the steam in the bubbles is greater; hence too, water will boil at a much lower temperature if the pressure of the atmosphere be diminished, as is the case on high mountains.

4. **Latent Heat.**—When cold water is placed in a vessel over the fire, heat from the fire is communicated to the water, which gradually becomes hotter till it reaches the boiling-point; but, after the water boils, the temperature of the water does not rise. What, then, becomes of all the heat that continues to be communicated to it? We noticed in Section 1 the manner in which different modes of energy could be converted into heat: this is a case of the reverse process; here heat is converted into motion. For a certain amount of heat a certain amount of work is done in pulling the particles of the liquid asunder. The heat which is consumed in this way after a liquid has been raised to the boiling-point—that is, heat which goes to form vapour without raising the temperature of the liquid or of the steam—has been called *latent*, from the notion, at one time entertained, that heat was a fluid, and, consequently, that the heat which seemed to be lost in this way concealed itself in the vapour. The same thing takes place when a solid is being reduced to a liquid. When heat is applied to a piece of ice, its temperature does not rise above the point at which it began to melt till every bit of it is melted. The heat thus absorbed in the melting of ice, is called the latent heat of water; and that absorbed in converting water into steam, the latent heat of steam. When this latent heat is lost in any way, the repulsion existing among the particles diminishes, cohesion regains the mastery, and the steam returns to the form of water, or water to that of ice. It is on this principle that distillation is accomplished. The *still* usually consists of a copper boiler, in which the fermented liquor is converted into vapour; of a pipe, which conveys the vapour from the top of the boiler; and of the *worm*, a coiled metal tube packed in a vessel through which there is a constant flow of cold water. The vapour arising from the boiling liquor in the copper is deprived of its heat in passing through the tube in the cold water; in consequence of this, it assumes again the liquid form, and drops or runs in a small stream from the end of the worm into a vessel placed to receive it.

5. **Conduction and Radiation.**—Just as light is the vibratory motion of the particles of a luminous body, and reveals itself by affecting the nerves of the eye; so it is this vibratory motion of the particles of a hot body, when communicated to the nerves, which causes the sensation of heat. These vibrations pass in all directions, and are hence called *radiant heat.* (See OPTICS, p. 25.) Again, as sound is transmitted by solids as well as by the air, so heat is transmitted by solids. When the end of a poker is placed in the fire, a vibratory motion is imparted to the atoms of that end; but this motion is communicated from atom to atom, till the other end also becomes heated. Metals shew the greatest facility in the passing of heat in this way; in other words, they are the best *conductors* of heat. The principle on which heat is transmitted through a fluid, as described at p. 39, and represented in the figure there, is called *convection,* because the particles of the body change their position, and, as it were, *convey* the heat; in the *conduction* of metals, no particle changes its position, the motion is merely passed from one to the other.

Having hitherto treated of the heating of a body, we will now consider the process of *cooling.* The motion going on among the atoms of a heated body is communicated to the ether, and the heat is said to *radiate;* thus the hot body expends energy, the motion of its own atoms gradually diminishes, and it is said to cool. Suppose, then, it were desirable to keep it from cooling, what could be done to prevent it? If the hot body were covered with another, the heat must first be conducted through this covering before it can be radiated. Now, different bodies have different powers of conduction, so that if a hot body be covered with a bad conductor, it will be kept hot for a long time. This is the object of wearing clothes—not to warm one's body, but to keep its heat from being radiated. When a piece of red-hot metal is exposed to the air, the heat radiates from the outside, and the outer coating of cooled metal becomes a conductor to the heat in the interior. When the body cooling is a bad conductor, which is quite a different thing from the radiation of heat from the outside, the internal heat is preserved for a long time. The lava that runs as a red-hot liquid from volcanoes, and spreads out in great sheets, after cooling on the surface, so that people may walk over it, retains its heat under this crust for years, because it is a bad conductor.

6. **Evaporation and Dew.**—One of the most interesting phenomena connected with heat is DEW, the nature of which will be perfectly intelligible after the above explanations. When treating of the heating of liquids, we saw that, with a degree of heat much less than what would raise a liquid to the boiling-point, vapour is formed at the surface of the liquid. The formation of vapour in this way is called *evaporation.* The heat of the sun is continually causing evaporation from all bodies of

water, or from everything wet; hence it is that anything wet by and by becomes dry, and even water in an open vessel will dry up. There is always more or less of this vapour in the air, even when the sky is clearest. It is only when the vapour, from being cooled in colder air, becomes partially liquefied, that it appears as *fog*, *mist*, or *cloud*. Dew, however, is not fog or mist deposited on the ground. After the sun has set on the evening of a hot summer day, the heat of the ground radiates into the air, or the grass, say, becomes cool, while the heat from the interior is not conducted quickly enough to keep up the temperature. The vapour in the air, coming in contact with this cooled surface, is now condensed into the watery particles of dew. One of the most remarkable things about dew is, that it is not deposited, at least to the same extent, on a cloudy night as under a clear, cloudless sky. This, at first sight, seems a contradiction, but only on the supposition that the moisture falls from the clouds, not when we remember how it is really formed. For the clouds radiate back to the earth the heat which has been radiated from it; so that the surface of the earth does not become colder than the air above it, and therefore the vapour is not condensed. Heat is always transmitted from one body to another which is colder. As was seen above, a certain amount of heat or of motion communicated to ice expands it into water, and a further amount expands the water into vapour. When the surface of the earth is colder than the air containing vapour, the heat of that vapour is transmitted into the ground, and the vapour becomes water or dew; and if the ground is extremely cold, the heat in the water keeping it in the liquid state, is further transmitted into the ground, the watery particles become solid and receive the name of *hoar-frost*.

PHYSIOLOGY OF THE HUMAN BODY.

The Human Body is a most skilfully contrived machine, composed of a great number of different parts, or *organs*,[1] all admirably adapted for the work they have to do, or, as it is technically expressed, the *functions* they have to perform. Thus, the limbs, the eyes, the ears, and the nose are organs which respectively perform the functions of motion, seeing, hearing, and smelling.

The functions performed by the organs of the body are of two kinds: (1) those that have to do with the building up and keeping in repair of the body itself; (2) those that bring the individual into connection with surrounding objects. The former have been called the functions of Nutrition, or of Organic Life, and include the digestion of the food, with the absorption of the nutritive materials contained in it, the circulation of the blood, and respiration; the latter are called the functions of Relation, or of Animal Life, and include all the forms of motion and of sensation. In the following lessons, however, we propose to describe first the bony framework, with its covering of muscles and skin; then, the apparatus for keeping the whole fit for use; and lastly, the nervous system, with the different forms of sensation which are the true links of connection between a human being and the outer world.

The Bony Skeleton.

Bone is a hard substance, composed of two kinds of material, an animal matter, called *gelatine*,[2] and a mineral or earthy matter, consisting principally of lime. To the former it owes its elasticity and toughness, and to the latter its hardness. The general appearance of bone is that of a network of minute canals, usually running lengthwise, and connected here and there by cross branches. Towards the outside, the substance of the bone is harder and more compact; and the whole is covered with

[1] From Greek *organon*, an instrument.

[2] From Latin *gelo*, to freeze, because the liquid gelatine takes the consistence of jelly when cold.

a membrane, called the *periosteum.*[1] The long, roundish bones of the legs and arms have this peculiarity, that they are hollow in the middle, and are filled with a soft, fatty substance, called *marrow.*

The skeleton is divided into the head, the trunk, and the extremities.

1. **The Head.**—The bony framework of the head, called the *skull,* is divided into two parts, the cranium and the face. THE CRANIUM[2] is the shell which contains the brain, and is composed of eight bones, of which the following six form its top and sides: *the frontal* or *coronal bone,* so called from Latin *corona,* a crown, because it forms the crown of the head, marked 1 on fig. 41; *the two parietal bones,* so called from Latin *paries,* a wall, because they form the walls or sides of the head, of which only one, marked 2, is seen in the figure; *the occipital bone,* from Latin *occiput,* the back part of the head, marked 3; *the two temporal bones,* from Latin *tempus, temporis,* the temple, marked 4. The base is formed by other two, *the sphenoid,* marked 5, *and the ethmoid,* not visible in the figure. The sphenoid, from Greek *sphēn,* a wedge, is so called because it wedges in and locks together all the bones of the head and face, being attached to fourteen distinct bones; and the ethmoid, from Greek *ēthmos,* a sieve, from its being perforated with a large number of holes, for the passage of nerves from the brain to the face, and of blood-vessels into the brain. It will be observed that the bony plates forming the upper part of the cranium are joined by ragged edges. These joinings are an elaborate system of *dove-tailing,* binding together the different pieces as firmly as if the whole were one, while certain purposes are also served by the cranium consisting of separate pieces. At the sides of the skull, some of the bones overlap each other, those above being supported by those beneath. Altogether, the bones of the skull form an arched or vaulted covering of extraordinary strength for the protection of the brain.

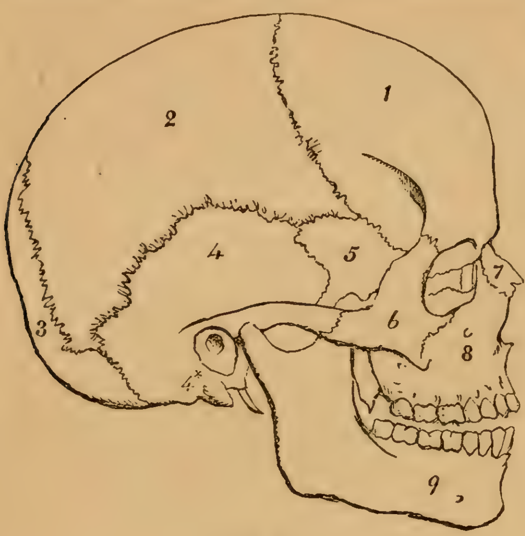


Fig. 41.

THE FACE is made up of fourteen bones, all of which, except the lower jawbone, are immovably fixed to each other, and to the bones of the

[1] From Greek *peri,* about, and *os,* a bone.
[2] Latin *cranium,* Greek *kranion,* from *kara,* the head.

cranium. By their union these bones form five cavities, which contain and protect the organs of sight, smell, and taste. The two principal bones are the upper *maxillary*[1] or *jaw* bones, marked 8 on fig. 41. Overlapping, and joined to them at the sides, are the two *malar*[2] or cheek bones, marked 6. These are joined behind to the two *palate*[3] bones, which form the back part of the roof of the mouth. The inside walls of the cavities for the eyes are partly formed by two small bones, called the *lachrymal*[4] bones, because there are holes through them for the passage of the ducts or canals which convey the *tears* from the eyes to the nose. The greater part of the nose is formed of cartilage or gristle, so that the bony part, formed of the two *nasal* bones, marked 7, is not very prominent. The nasal cavity is divided into two by a partition, which is partly formed by a bone called the *vomer*,[5] from its resemblance to a ploughshare; and its outer walls are formed of two small *turbinated*[6] bones, which are thin bony plates, in the form of a *scroll* or horn, the use of which will be explained when we treat of the organ of smell. Last of all, comes the *lower maxillary* or lower jawbone, marked 9.

2. **The Trunk.**—The most important part of the trunk is the SPINE[7] or backbone, so called from its spikes or points. It consists of a large number of small pieces so jointed together as to make it exceedingly flexible. Each of the pieces is called a *vertebra* [Latin, 'a joint'], and is attached to the two between which it lies by strong elastic *ligaments*;[8] while between each pair is a cushion of cartilage, which is thickest in the lower part of the spine, and serves a very important purpose. When the body is jolted in any way, for example, in jumping from a height, these cushions act like the buffers of a railway train, and neutralise the shock. From its being composed of these vertebræ, the spine is called the *vertebral column*. Each vertebra is perforated with a round hole; and from the manner in which they are joined together, these holes form a continuous canal, which contains and protects the *spinal cord*. This substance, although sometimes erroneously called the spinal *marrow*, is quite distinct from the real marrow found in the long bones of the legs and arms. It is, in fact, next to the brain, the most important part of the nervous system, in connection with which it will afterwards be described. Behind the backbone are three rows of projections; one in the centre, forming the ridge felt along the back, and seen farthest to the right in the figure, called the *spinous processes;* and one on each side of these, called the *transverse processes*. In the whole

1 From Latin *maxilla*, diminutive of *mala*, a jaw.
2 From Latin *mala*, a jaw.
3 From Latin *palatum*, the roof of the mouth.
4 From Latin *lachryma*, a tear.
5 Latin *vomer*, a ploughshare.
6 From Latin *turbo, turbinis*, a whirl.
7 Latin *spina*, a thorn.
8 From Latin *ligo*, to bind.

column there are 33 vertebræ. At the top are 7 *cervical*[1] vertebræ, or vertebræ *of the neck.* The topmost, or first cervical, is termed *atlas*, because by it the head is properly borne up, as the earth was by the fabled god Atlas. The second cervical is called the *axis*, because it is the proper axis or joint of the neck, the joint between it and the *atlas*, which is a pivot-joint, being that which enables the head to turn round. Next to the cervical are the 12 *dorsal*[2] vertebræ, or vertebræ *of the back;* after which come 5 *lumbar*[3] vertebræ, or vertebræ *of the loins.* All the above mentioned may be separated from each other, and are called *true vertebræ;* the rest, namely, the 5 that are ossified together, and form the *sacrum*, or sacred bone, and the 4, also united, that form the *coccyx*,[4] so named from its resemblance to the beak of the cuckoo, are called *false vertebræ.*

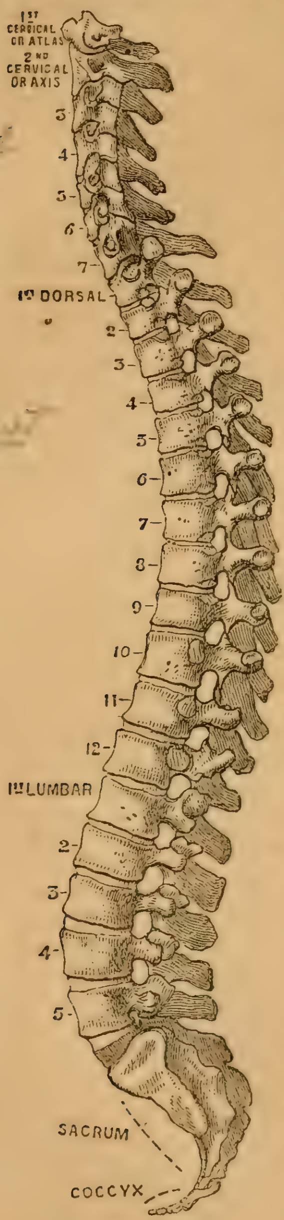


Fig. 42.

It is interesting to know that the skull is merely a prolongation of the backbone, and consists of four of the segments or vertebræ described above. The hollow space which contains the spinal cord is in these four expanded into a capacious chamber (the cranium) for containing the enlargement of the nerve-substance called the brain. The four segments of the spinal cord which correspond to the four vertebræ, and which form the basis of the brain, give off the nerves of smell, sight, taste, and hearing.

The bony part of the trunk is completed by THE RIBS, which are 24 elastic arches of bone, 12 on each side, attached behind to the dorsal vertebræ, and in front to the *sternum*,[5] or breastbone, by a cartilaginous ligament. It will be seen from fig. 43 that the sternum does not extend far enough down to allow of all the ribs being directly attached to it; there are, in fact, only seven thus attached, which are therefore called *true* ribs. The other five are called *false* ribs. Of these, the ends of three are indirectly attached to each other and to the sternum by a

[1] From Latin *cervex, cervicis*, the neck. [2] From Latin *dorsum*, the back.
[3] From Latin *lumbus*, a loin. [4] Latin, 'a cuckoo.' [5] Latin, 'the breast.'

cartilaginous band ; the other two are unattached to anything in front, and are therefore called *floating* ribs. The ribs, along with the sternum,

THE HEAD.

The Cranium—
1 Frontal bone.
2 Parietal bones.
1 Occipital bone.
2 Temporal bones.
1 Sphenoid bone.
1 Ethmoid bone.

The Face—
2 Upper maxillary bones.
2 Malar bones.
2 Palate bones.
2 Lachrymal bones.
2 Nasal bones.
The vomer.
2 Turbinated bones.
1 Lower maxillary bone.

THE TRUNK.

The Spine—
7 Cervical vertebræ.
12 Dorsal vertebræ.
5 Lumbar vertebræ.
The sacrum = 5 false.
The coccyx = 4 false.

The Ribs—
7 True ribs.
3 False ribs.
2 Floating ribs.

THE EXTREMITIES.

The Arm and Hand—
The humerus.
The radius.
The ulna.
8 Carpal bones.
5 Metacarpal bones.
14 Phalanges.

The Leg and Foot—
The femur.
The tibia.
The fibula.
7 Tarsal bones.
5 Metatarsal bones.
14 Phalanges.

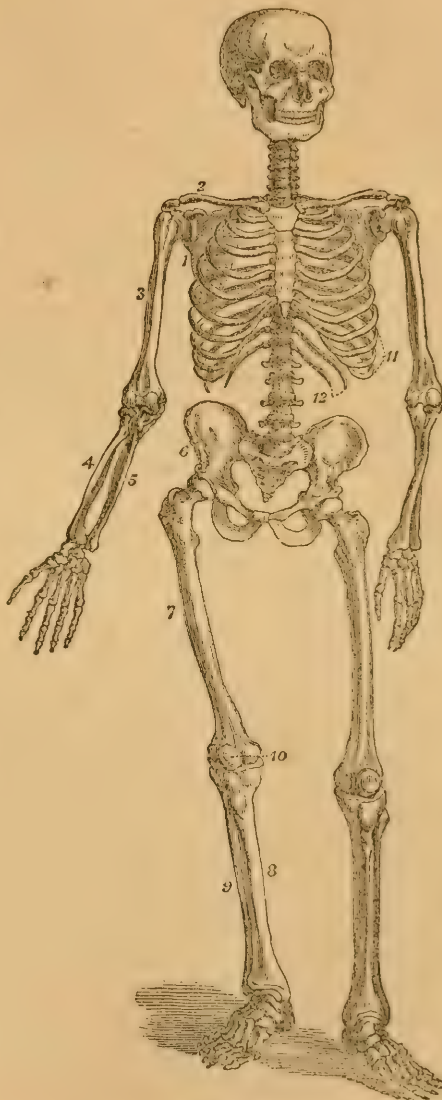


Fig. 43.

form the bony framework of the chest, in which are placed the heart and lungs.

3. **The Extremities.**—The extremities may be divided into upper and lower, or the arms and the legs. Each member consists of a set of extended

movable bones, which are worked by means of muscles, like so many levers, and of a bony framework to which the limbs proper are attached, and which is fixed to the trunk.

(1) THE UPPER EXTREMITIES—THE ARMS.—The bone in which is the socket for the first bone of the arm is a triangular, flat bone, lying on the back of the dorsal ribs, and called the *scapula* [1] (1 in fig. 43). It lies quite freely on the ribs, and so tends to give freedom of motion to the arm; but it is very firmly supported by the *clavicle* [2] or *collar-bone* (2 in fig. 43), which is attached to a projection on the scapula. The socket in the scapula for the reception of the head of the arm-bone, is a shallow cup-like cavity, into which the round head of the bone fits; and in consequence of the shallowness of this socket, the arm has perfect freedom to move in every direction. Yet this arrangement has its disadvantage, from the greater danger there is of the head of the bone being dislodged from its place, as not unfrequently happens, security being thus slightly sacrificed for freedom of motion. It will be seen that in the case of the hip-joint, on the other hand, through the greater depth of the socket, freedom of motion is sacrificed for security and strength. THE ARM itself is divided into three parts—the arm proper (from the shoulder to the elbow), the fore-arm (between the elbow and the wrist), and the hand. The bony part of the arm proper is a single hollow bone, called the *humerus* [3] or shoulder (3 in fig. 43). The shoulder-joint has already been described; at the lower end the bone is flattish, to allow of its being jointed at the elbow to the two bones of the fore-arm—namely, the *radius* [4] and the *ulna* [5] (4 and 5 in fig. 43). The ulna is connected with the humerus by a common hinge-joint; while the radius has a pivot-joint, with a cavity in the end to receive a rounded knob on the end of the humerus, so that it is capable of a rotatory motion.

To these two bones at the wrist is attached THE HAND, which consists altogether of 27 bones. First come the 8 *carpal* [6] or wrist bones, which are arranged in two rows—3 to 10 in fig. 44, 1 and 2 being the ends of the radius and ulna. The upper surface of the first row is convex, and fits into a cup-like socket in the lower end of the radius. The first carpal bone, 3, of the first row supports, by means of 7 and 8 in the second row, the bones of the thumb and forefinger (I and II); 5 in the first row, in like manner, supports, through 10 in the second row, the bones of the little finger and of the one next to it; 4 and 9 in the first and second rows, support the bones of the middle finger. These 8 carpal

[1] Latin *scapula* = *spatula*, diminutive of *spatha*, a spade.

[2] From Latin *clavicula*, diminutive of *clavis*, a key, so called from its resemblance to a Roman key.

[3] Latin, 'the shoulder.'

[4] Latin, 'a spoke of a wheel.'

[5] Latin, 'the elbow.'

[6] From low Latin *carpus*, the wrist.

bones are very closely packed and tightly bound together with ligaments, so that the wrist is as strong as if it consisted of but a single bone; while, at the same time, the elasticity obtained by having so many bones movable on each other, neutralises, to a great extent, a shock occasioned by falling on the hands. Next to the carpal bones come the 5 *metacarpal*[1] (11—11), which form the comparatively long bones of the back of the hand. Last of all, come the 14 *phalanges*[2] or bones of the fingers (12—14), a name also applied to the corresponding bones of the foot.

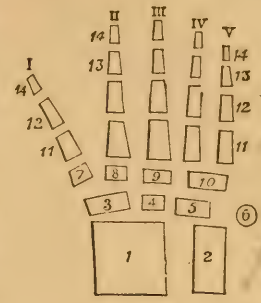


Fig. 44.

(2) The Lower Extremities—the Legs.—The plan of the bony framework of the legs is very similar to that of the arms. The principal point of difference is, that the structure of the former is stronger, in order to support the weight of the body; strength and solidity being in the lower limbs of even more importance than freedom of action, which we saw to be so well provided for in the arms. The whole framework to which the lower extremities are attached, and which also forms a *basin*-like cavity for supporting the contents of the abdomen, is called the *pelvis*[3] (6 in fig. 43). In a full-grown person, the pelvis consists of a single bone, called the *os innominatum* or 'nameless bone.' On the under side of the spreading part of the pelvis is a cup-like socket, to receive the rounded head of the thigh-bone. The deepness of the socket here, while it does not allow so much freedom of action to the leg, makes the joint a very secure one (compare what is said on the shoulder-joint, page 48). In the thigh there is only one bone, the *femur*[4] (7 in fig. 43), which is jointed at the knee to the two bones of the leg proper. These are the *tibia*,[5] or shin-bone (8 in fig. 43), the larger of the two, and the *fibula*[6] (9 in fig. 43). It is the tibia alone which supports the thigh-bone, so that the fibula, as its name indicates, forms merely a sort of connection between the knee-joint and the ankle, and serves for the attachment of muscles. On the knee-joint, which is a pure hinge-joint, is a small separate bone, the *patella*,[7] or knee-pan (10 in fig. 43), the object of which is to change the direction of the tendons of the muscles that come down from the front of the thigh to be inserted in the tibia, so as to enable them to act more advantageously, according to the principle afterwards explained (see p. 52).

The Foot consists of 26 bones, which are arranged on a plan very similar to, if not identical with, that of the hand. In the hand, we had

[1] From Greek *meta*, after, or coming after.
[2] From Greek *phalangx*, the lines of an army drawn up in battle array.
[3] Latin, 'a basin.' [4] Latin, 'the thigh.' [5] Latin, the 'shin-bone.'
[6] Latin, 'that which fastens two things together.'
[7] Latin, diminutive of *patina*, a pan or dish.

carpal and metacarpal bones; in the foot, we have *tarsal* and *metatarsal;* and in both there are *phalanges.* The *tarsal*[1] bones, seven in number, compose the heel and the hinder part of the instep. Fig. 45 exhibits the beautiful arch which is formed by the bones of the foot, called the *plantar* arch from Latin *planta,* the sole of the foot. On the top of the arch is the large bone, D, which supports the tibia of the leg, the end of which is seen in the figure. The bone, D, is supported principally by the heel-bone F, the largest bone of the foot, but also, in front, by the bone E, and the ligament B, which binds E to F. D, E, and F correspond to bones 3, 4, and 5 in the hand; while in front, and at the outer side of E, are four bones corresponding to 7, 8, 9, and 10 in the hand. In the front part of the instep are the five *metatarsal* bones corresponding to 11—11 in the hand. To the metatarsal bones are jointed the *phalanges,* or bones of the toes, each toe having three, except the great toe; just as in the hand each of the fingers had three phalanges, but the thumb only two.

Fig. 45.

Such is an outline of the bones composing the framework of the body. The coatings of flesh or muscle which cover this skeleton, and the skin, the outer covering of the whole, are now to be described.

The Muscles.

Muscular Tissue is the soft, fleshy covering of the bones, by means of which all the movements of the body are made. This faculty which it possesses of causing motion is due to its contractility. A mass of this tissue attached to certain bones, is called a *muscle.* When a muscle is closely examined, it is seen to consist of a great number of fibres regularly arranged lengthwise. It is further seen that these fibres are connected together in bundles, of different sizes, enclosed

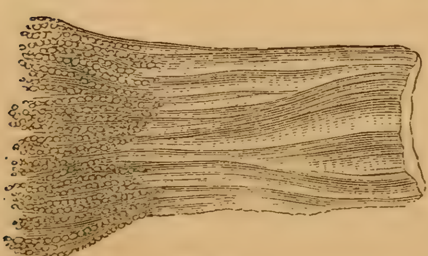


Fig. 46.

[1] From low Latin *tarsus,* Greek *tarsos,* the instep.

in sheaths of another kind of tissue. Fig. 46 represents such a bundle of fibres. The individual fibres, again, are streaked in two ways—lengthwise and crosswise. When separated from each other, they often split up into *fibrillæ*,[1] or little fibres, as seen in fig. 47. Other fibres, when extended, separate, according to the cross streaks, into discs, as seen in fig. 47, *a*, *b*; and when this separation takes place both ways at once, the fibre is separated into a mass of particles, *b′* in fig. 47. When a muscle is being contracted, these cross discs of the individual fibres become more closely squeezed together, and the fibre becomes thicker as it is shortened, in a manner similar to what is seen to take place in the body of a worm, when it is drawing itself up after having put forward its head.

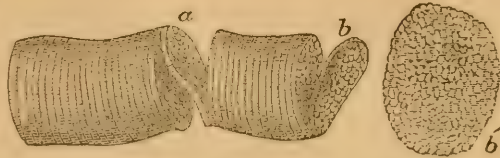


Fig. 47.

The muscles are attached to the bones by means of *tendons*,[2] which are white, smooth, non-elastic bands at the ends of the muscles, of a different structure from the muscle itself. Of the two component parts of fibrous tissue, the elastic and the non-elastic, only the non-elastic, which is white, is found in tendons ; a tendon being formed of fibres of this white tissue, one fibre coming from each fibre of the muscle. The tendon itself is a tough, white mass, attached to the bones by the individual fibres becoming fixed in depressions in the bones, and also by becoming amalgamated with the hard outer part of the bone called the *periosteum*. The muscle being thus attached at its ends to two bones, a distinction is made between the two ends ; the point of attachment to the less movable bone is called the *origin*, while that to the bone specially to be moved is called the *insertion;* thus, the muscle which bends the elbow is attached to the shoulder and to the fore-arm ; the point of attachment of this muscle at the shoulder is its origin, and the point of attachment in the fore-arm its insertion. Muscles such as the one here alluded to—that is, those that bend joints, the best example being the muscles that bend the fingers on the palm—have a particular name, *flexors*, or benders, from Latin *flecto*, to bend. Where such muscles exist, there is always, of course, another set that reverse this bending action, or extend the bones connected with the joint, and are hence called *extensors*, from Latin *extendo*, to extend ; such are the muscles that open the hand, by extending the fingers. Muscles which act in opposition to each other in this way, as flexors and extensors, are said to be *antagonistic*, or the one is said to be the *antagonist* of the other.

The various bones acted on by the muscles are like so many levers

1 Latin, diminutive of *fibræ*, threads. 2 From Latin *tendo*, to stretch.

(Physics, p. 11); the fulcrum is generally a joint; the power is a muscle, the force being exerted by contraction, and the weight the farther end of the bone or limb. They are all levers of the third kind (Physics, p. 9), the power acting between the weight and the fulcrum, and therefore acting at a mechanical disadvantage—that is, a power greater than the resistance has to be exerted in order to accomplish the movement. There is another disadvantage which the muscles labour under in working, arising from their being attached to the bones in an oblique direction; but this is partly done away with by means of the peculiar formation of the bones—that is, by a thickening at the joints. Thus, in fig. 48, A, when a bone (*o*) is to be moved, the tendon (*i*) of the muscle (*m*) comes over the thickened part of the bone at the joint, and is attached immediately below it, so that the attachment of the muscle is more nearly perpendicular than it would otherwise have been. By this means the bones turn more freely on each other; otherwise the ends of two bones would merely be pressed together, as in fig. 48, B. As regards the mechanical disadvantage from the nature of the lever, it is compensated for, we know, by the gain in velocity (Physics, p. 10), as will be seen from the consideration of one case, the raising of the fore-arm. The lever to be raised is the fore-arm, *bc*, the weight being whatever is in the hand; the fulcrum is at the elbow-joint; the power is in the muscle *d*, inserted at *e*. Now, it is clear that when the muscle is contracted a little, the hand will be raised a distance proportioned to the length of the arm, and, of course, must move proportionally quicker; while, at the same time, the power exerted by the hand requires an exertion on the part of the muscle greater exactly in the same proportion (Physics, page 11).

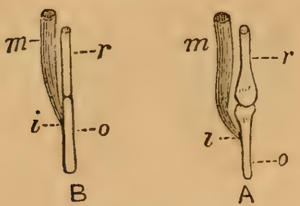


Fig. 48.

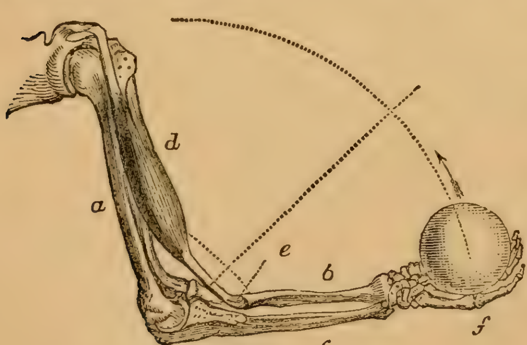


Fig. 49.

This is the general principle on which the muscles of the body act.

Principal Muscles of the Body.—Space will not permit a detailed description of the various muscles of the body: a few of the principal muscles only can be mentioned. The various emotions of pleasure, anger, wonder, scorn, &c., are expressed in the face by a smile, a frown, a raising of the eyebrows, a curl of the lip, &c., which are caused by the action of the

muscles round the eyes and the mouth, of those in the cheeks, and of those that raise and depress the eyebrows and the nose, &c. The most important muscles of the skull are those attached to the lower jaw, by which the food is chewed. The largest of these, called the *temporal* muscle, is attached to the flat surface of the temporal and parietal bones, and is assisted by another, called the *masseter*, a Greek word meaning 'the chewer.' The head is kept balanced on the neck by means of strong muscles, the constant exertion of which is necessary to keep it erect. The body is kept erect on the legs by a set of muscles attached to the thighs and to the bones of the pelvis, which do the double duty of moving the legs and of supporting the trunk, as well as of raising it to an erect posture on being bent down.

The arm is raised from the side by a large muscle on the shoulder, called the *deltoid* from its resemblance to the Greek letter *delta*, Δ. From under it arise two muscles which respectively bend and extend the fore-arm. That which bends the fore-arm is called the *biceps*[1] or two-headed muscle, and that which extends it the *triceps*[2] or three-headed muscle. The biceps forms a great part of the fleshy mass in front of the arm, and the triceps forms the fleshy mass at the back. The turning movements of the hand are effected principally by the radius. The turning of the palm of the hand *downward* is called *pronation*,[3] while turning it *upward* is called *supination*;[4] and the muscles by which these movements are performed are called respectively *pronators* and *supinators*. The wrist and hand are bent upon the fore-arm by three muscles, which have their origin from the inner end of the humerus, and one of which spreads out into a fan-like membrane on the palm of the hand. Under this palmar membrane lie the flexor muscles of the fingers. The antagonists of these flexors are the common extensors of the fingers, a special extensor of the fore-finger, the muscles of the thumb, accumulated in the *ball* of the thumb, which move it in every direction, and several other muscles of less importance.

The thigh is raised and advanced by means of two muscles, which descend in front of the pelvis—one from the lumbar vertebræ, and one from the upper expanded surface of the pelvis. The antagonists of these, the muscles which draw back the thigh, have their origin on the back and under surface of the pelvis.

The muscles which bend the knee proceed from the lower border of the pelvis and the back of the thigh-bone, and are inserted in the sides of the tibia and fibula, a little below the knee. The tendons of these are felt behind the knee, and are known as the *hamstrings*. The extensors of the

1 From Latin *bis*, twice, and *caput*, a head.

2 Latin *tres*, three, and *caput*, a head.

3 From Latin *pronus*, with the face downward.

4 From Latin *supinus*, with the face upward.

knee, the muscles that straighten the knee-joint, proceed from the front of the pelvis and from the femur itself, forming the fleshy mass in front of the thigh.

The most important muscle of the foot is that which forms the calf of the leg (A, fig. 50). It is of immense strength, because in raising the heel it has to raise the weight of the whole body. It is attached above to the bones of the thigh and leg, and is inserted by the tendon of Achilles, as it is called (*a*), to the heel-bone. Another muscle, B, is attached to the tibia, and inserted in one of the bones of the arch of the foot; and a third is attached to the fibula, and inserted in the outer metatarsal bone. These two last being inserted into the outer and the inner edges of the instep, turn round the outer and inner ankle respectively. The raising of the toes, the turning of the foot outward, and the straightening of the sole, are effected by other two muscles (F, fig. 50, and a similar one on the other side), the tendons of which pass down in front of the inner and outer sides of the ankle, and are inserted in the inner and outer edges of the instep respectively.

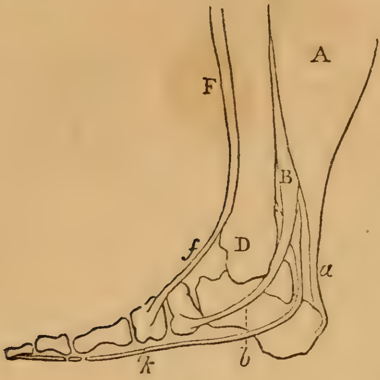


Fig. 50.

The Skin, Hair, &c.

The Skin consists of two layers, the true skin and the scarf-skin; the former being called the *dermis*[1] or *cutis*,[2] and the latter the *epidermis*[3] or *cuticle*.[4] The dermis forms the thick layer of the skin, and is a strong, supple, elastic membrane, formed of a compact kind of tissue, which, in its ordinary form, has a spongy appearance, being full of little cells. This tissue is composed of two elements—a yellow or elastic substance, and a white or inelastic, tough substance; and these substances are arranged in various proportions, according to the nature of the covering that is wanted at a particular place. The cutis also varies as to thickness, according to the amount of resistance or of protection required for the part covered; thus, on the sole of the foot, the cutis is very thick, and is composed principally of the tough white substance. On the outer surface of the cutis are a number of small flexible elevations, called *papillæ*[5] or pimples, which will be mentioned again in treating of the

1 From Greek *derma*, skin.
2 Latin, 'skin.'
3 From Greek *epi*, upon, *derma*, skin.
4 From Latin *cuticula*, diminutive of *cutis*, skin.
5 Latin, diminutive of *papulæ*, pimples.

senses of touch and smell. Imbedded in the cutis are the sweat-glands,[1] which separate from the blood the fluid which appears on the skin when one is heated. These glands send forth their fluid by *ducts*[2] or canals of a spiral form. Besides these glands, there are, in the cutis, two kinds of *follicles*[3] or 'little bags' connected with the hair. These are the *hair follicles* proper, which are little pits in the cutis, in which the roots of the hair are developed; and the *sebaceous*[4] follicles, which are glands for the secretion of *a fatty matter* supplied to the hair when it comes above the skin, to prevent its being too much dried up. Each hair consists of a 'bulb' and a 'shaft;' and the shaft, again, consists of a soft, pith-like part in the middle, with an outer and harder layer. The bulb consists of a mass of the cells of which the cutis is composed, developed at the bottom of the follicle. The inside of the shaft contains something of the same kind; while its outer layer is simply these cells dried and turned into a scaly nature. This is, in fact, exactly the composition of the *epidermis;* the cells which are on the surface are dried and flattened into scales (as seen in the scurf thrown off the skin of the head, especially under the hair), so as to form a transparent, insensible varnish for the sensitive cutis. So, too, the *nails* are formed; the horny substance of which they consist being composed of these dried and hardened cells, which are being continually pushed outward by a development of fresh cells at the root of, and under, the nail.

Nutrition.

Having described the framework of the body, we now proceed to consider the manner in which it is kept in repair. When anything is said to be kept in repair, it is understood that it is already made or formed; and so here it is understood to be a full-grown human body that is to be nourished. And this process is different from either 'growth' or 'development.' Development is the process by which each part of the body is first formed or so changed as to be adapted to perform a higher function. Growth, again, is the mere increase, principally in size and weight, without any change in form, of the different parts by the addition of matter similar to that composing them. During the whole period of life, there is continually going on in all parts of the body a process of decay, and the casting off of substances which have become useless and even positively injurious in the economy of the body. Nutrition, then, includes the different processes of Digestion, Absorption, Secretion and Excretion, Circulation of the Blood, and Respiration, by

[1] A *gland* is an organ, having blood-vessels, absorbents, and nerves, for secreting a certain fluid from the blood.

[2] From Latin *duco*, to lead.

[3] Latin *folliculus*, diminutive of *follis*, a bag.

[4] From Latin *sebum*, fat.

which the decaying matter of the body is carried away and fresh material supplied in its place.

The process of Digestion may be divided into the following parts—1. The Mastication of the food; 2. The Insalivation; 3. The Deglutition or swallowing; 4. The Chymification or digestion in the stomach; 5. The Chylification or digestion in the intestines; and 6. The Absorption of the chyle.

1. *Mastication* or chewing is performed by the teeth. These are small, hard, white bodies, fixed in the jaws, so as to come against each other, and reduce the food by cutting and bruising it. They are formed of three substances—dentine, cement, and enamel. The inside and body of the tooth are formed of *dentine*, so called from Latin *dens, dentis*, a tooth; outside of this is a layer of cement, which is softer than dentine; but where the tooth appears above the jaw, the cement is replaced by a hard *enamel*, which forms a very strong protection for the exposed part of the tooth, called the *corona* [Latin, 'a crown']. There are in all 32 teeth in man, and these are of three kinds: the *incisive*[1] or cutting teeth, in front; the *canine*[2] or dog-teeth, next to the cutting-teeth on each side; and the *molars*[3] or grinders, behind, ordinarily called *double* teeth, because they have a double edge, instead of a single one like the front teeth. The *incisors* have a single fang or root, and the *corona* is bevelled behind, so as to present a sharp, chisel-like cutting edge. There are two on each side of both jaws, that is, eight altogether, and they are used for biting the food, *aa*, fig. 51. The *canine* teeth, so called because they are very prominent in dogs, have a single root, and their corona is more pointed than edged, *bb*, fig. 51. The *molars* are divided into *true* and *false*. First come (in a half-jaw, as A, fig. 51) two *false molars* or *premolars*,[4] so called because they are placed *before* the *true* molars, *c*, which are of a form between that of the canine teeth and the true molars. Last of all come the true molars, *d*, which are larger than any of the other teeth, and have a corona well adapted for bruising the food.

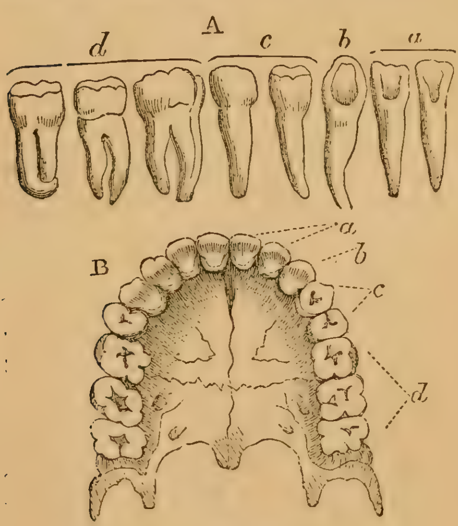


Fig. 51.

[1] From Latin *incido, incisum*, to cut.
[2] From Latin *canis*, a dog.
[3] From Latin *molo*, to grind.
[4] From Latin *pre*, before.

The different kinds of teeth with which man is furnished indicate that his food is intended to be of a mixed nature. Those animals that live entirely on flesh have back teeth with sharp, jagged edges, which fit into each other, and act very much like scissors, tearing and cutting their food; partly of this nature are the incisive, canine, and premolar teeth of man. Those animals, again, that live entirely on vegetable food, have broad-headed teeth, very uneven and rough on the top, the joint of the jaw having a freer motion, so that the jaws rub on each other sidewise, and thoroughly bruise the food, as if with millstones. This kind of teeth is found in the molars of man; and the under jaw has this side-motion, to a certain extent.

2. *Insalivation.*—While the food is being chewed, it is mixed with *saliva* or spittle. This is a colourless, tasteless fluid, which is secreted by three pairs of glands, one pair in front of the ears, a second under the jaw, one on each side, and a third under the tongue, one on each side. The saliva, by moistening the food, renders it more easily swallowed; the moisture also helps in the separation of the particles of the food, and in the sense of taste. Another purpose served by the saliva is the conversion of the starchy matter of the food into sugar, which promotes its absorption.

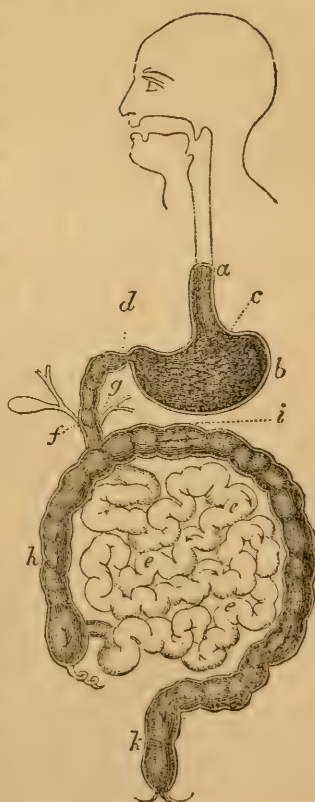


Fig. 52.

3. *Deglutition.*—The *pharynx*[1] or entrance to the gullet, is closed, while the food is being chewed, by the soft palate, which is a fleshy valve hanging down from the roof of the mouth. As soon, however, as the food is properly chewed and mixed with saliva, it is pushed backward by the tongue, and the soft palate is immediately drawn backward and upward, and the food enters the pharynx. As soon as this happens, it is beyond recall, except by the involuntary action of coughing, for it is carried into the stomach by the action of the muscles of the gullet, which are excited by the presence of the food. The principal muscles of the gullet are circular, or surround it like a number of elastic rings; so that, when a mouthful of food has been pushed into the pharynx by the

[1] Greek, 'a cleft.'

tongue, it is moved onward through the gullet by the continual contraction of the elastic rings behind it. In this manner, the food finds its way into the stomach. The course taken by the food will be best understood from an outline sketch of the Alimentary Canal (fig. 52), which is the whole digestive apparatus through which the food passes. The gullet (*a*), in its passage to the stomach, passes through an opening in the *diaphragm*,[1] a large, flat muscle, which forms the partition between the chest and the abdomen. Immediately below this, it enters the stomach, a large, muscular bag (*b*), widest at the end where the gullet enters (*c*); from the narrower end proceeds the smaller intestine, which is generally about twenty feet long, and, rolled up in numerous folds (*e*, *e*), occupies the middle of the abdomen. The small intestine is attached to the large intestine (*h*, *i*, *j*, *k*), which is about five or six feet long, and passes upward on the right side of the folds of the small intestine (the right side of the figure is the left side of the man), across to the left, and then down to the *anus* or lower orifice of the alimentary canal, by which its contents are discharged.

4. *Chymification.*—When the food enters the stomach, the process of *digestion* immediately begins. This consists in the reduction of the food to a thoroughly broken-up, thin, pulpy mass, so as to allow of the nutritive part being received into the system. For this object, it is mixed with a fluid, called the *gastric*[2] juice, which is secreted in a great many little bags in the walls of the stomach, and poured out whenever food enters the stomach. To facilitate this mixture, there is a provision made for stirring it about. The walls of the stomach are composed partly of strong muscles; and when the food enters, which it does at the upper left-hand corner (*c*, fig. 53), by the contraction of these muscles, it is pushed towards the right, along the top (*a*, *a*). When it comes to the right extremity, it is pushed back to the left, but now nearly in the middle (*b*); and when it comes back to the left, the opening being firmly closed by muscles, it is divided into two streams —one going along the top, and the other along the bottom. By this means, the food is thoroughly mixed with the gastric juice, and reduced to a half-fluid pulp, called *chyme* [Greek *chymos*, juice]. The gastric juice consists of two elements—an acid, and an organic matter called *pepsine*, from Greek *peptō*, to digest; and the uses of it are to dissolve and modify all animal

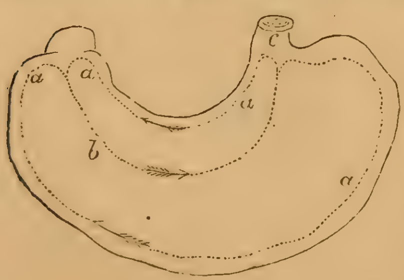


Fig. 53.

[1] From Greek *diaphrassō*, to divide by a partition. [2] From Greek *gastēr*, the stomach.

food, except fat, and all the blood-forming portion of vegetable food.

5. *Chylification.*—When a certain quantity of chyme has been formed in the stomach, the valve which closes the *pyloric*[1] orifice (*d*, fig. 52), or opening between the stomach and the small intestine, is opened, and it passes out; but no food is allowed to pass out that has not been properly mixed with and acted upon by the gastric juice. In the small intestine, the chyme is mixed with three new fluids—the *bile*,[2] the *pancreatic*[3] juice, and the *intestinal* juice. The bile is a greenish-yellow liquid, secreted by the liver, and kept stored in a little bag near it, called the gall-bladder, from which, as well as directly from the liver, it is discharged into the intestine, close to where the latter leaves the stomach, *f*, fig. 52. Its principal function is to digest the fatty part of the food, which the gastric juice does not act upon. The pancreatic juice is a fluid very like saliva, which is also poured into the intestine at the same place as the bile, *g*, fig. 52. One of its functions is to complete what was begun by the saliva—namely, to convert starchy matter into sugar. It also serves further to dilute the chyme, and performs a very important chemical process, too complex to be described here. The intestinal juice unites in itself the properties both of the saliva and of the gastric juice—namely, the power of converting starchy matter into sugar, and of dissolving all animal food but fat, and the blood-giving portion of vegetable food.

In the intestine, then, we have seen that there is a provision for reducing nutritious matter of every kind to a state fit for absorption, the fluid here acting on the food being compounded of the saliva, the gastric, the pancreatic, the intestinal juices, and the bile. And as the process of thus reducing the food is being carried on whilst the food moves through the intestine, so the nutritious part is being withdrawn by absorption. One part, which is perfectly reduced, and fit for passing into the system at once, is taken up by the blood-vessels (in the stomach as well as in the intestine); another part, which seems to be blood 'in an early stage of its formation, with a large excess of fatty matter,' is called *chyle* [Greek *chylos*, juice], and is taken up by the *lacteals*,[4] a system of absorbent vessels, so called from the white, milk-like appearance of their contents.

After the chyle has been taken up by the lacteals, there remain certain parts of the food which have been rejected as comparatively worthless for nutrition. This portion of the food, called the *fæces* [Latin, 'grounds'], passes from the smaller into the larger intestine, in which most of the

[1] From Greek *pylouros*, a porter, from *pylē*, a gate, and *ouros*, a guardian.

[2] Latin *bilis*, connected with *fel*, *fellis*, the gall-bladder.

[3] From Latin *pancreas*, a fleshy gland under and behind the stomach, by which the fluid is secreted, from Greek *pan*, all, and *kreas*, flesh.

[4] From Latin *lac*, *lactis*, milk.

remaining fluid is absorbed. This intestine, though not so long as the small intestine, is wider than it, because a greater capacity is required, on account of accumulation.

6. *Absorption.*—Both in the stomach and in the smaller intestine, part of the nutritive materials of the food is received directly into the system by the blood-vessels; but besides this, there is another system of absorption going on, on a more roundabout plan, by means of the *lymphatics*,[1] which are absorbent vessels that originate in all parts of the body. From the body in general, they collect the fluid which has escaped from the blood-vessels into the different tissues, as well as the particles of worn-out tissues, and convey both into the venous circulation near the heart. At their extremities, the lymphatics are spread out in a minute network, from which they pass to the lymphatic glands, or to a larger trunk. In passing through these glands, which are small solid bodies found in the course of the lymphatic vessels—for example, in the neck, the armpit, the groin, &c.—the fluid receives a part of its peculiar properties.

The *lacteals*, already mentioned, are simply the lymphatics of the smaller intestine; but the fluid they carry is called chyle instead of lymph. On the inner coat of the small intestine are a great number of small conical projections, called *villi*, from Latin *vellus*, a fleece of wool. At the points of these villi, the lacteals take their origin. They then pass between the two folds of the membrane which connects the intestine with the cerebral column, and make their way to a pouch or bag in the lumbar region, from which the *thoracic*[2] duct conveys the chyle upward along the spinal column to above the level of the heart; then crossing to the left side, it joins another vein by which its contents reach the heart.

Circulation of the Blood.

The process of digestion just described prepares a fluid called the Blood, which conveys nutriment to all parts of the body. It at the same time takes up all waste matter, which is carried to the lungs, where it is discharged, and a supply of new matter received from the air, as will be explained under Respiration.

To effect all this, a continual circulation of the blood is necessary, which is produced by a very simple but effective pumping apparatus called the Heart.

The blood itself consists of a nearly colourless fluid called the *liquor of the blood*, and, floating in this fluid, an immense number of round, flat particles called *globules*,[3] or *corpuscles*.[4]

[1] From Latin *lympha*, water.
[2] From Latin *thorax*, the chest.
[3] From Latin *globulus*, diminutive of *globus*, a ball.
[4] From Latin *corpusculum*, diminutive of *corpus*, a body.

The *liquor of the blood* consists of water in which are dissolved a quantity of a substance called *fibrine*,[1] a good deal of albumen, to which all the tissue-forming elements of the food are reduced, a quantity of fatty matter, and other organic substances, with a quantity of mineral matter, principally salt. The fibrine is the substance which coagulates in the blood (it may be seen by beating fresh blood with a stick, to which it adheres in fine threads—hence its name); and it is this property that forms the beautiful provision for the repair of injuries. Were it not for this power of coagulating, a great quantity of blood might be lost by the smallest cut or scratch. The purpose of the albumen, along with the fatty matter also in solution in the blood, is to be expended in keeping up the solid tissues of the body, by which it is being continually appropriated. The liquid in which the fibrine and albumen are dissolved has the power of absorbing gases, so that the 'liquor of the blood,' besides continually building up the tissues of the body, also conveys to them oxygen from the lungs, and carries back the carbonic acid which is set free in the tissues. But in this duty, the heaviest part of the work is performed by the properly solid part of the blood, the red corpuscles; and these, again, besides this function, are principally concerned in the production and renewal of the muscular tissue.

The apparatus by which the blood is conveyed to every part of the body, to perform the functions just described, consists of two systems of tubes to convey the blood, called blood-vessels, and the heart, which is in reality a force-pump of great power. The two sets of blood-vessels are the *arteries*, which carry the blood from the heart throughout the body, and the *veins*, which bring it back to the heart. There is, besides this, a second circulation. When the blood returns to the heart, it is unfit to be again sent out until it be purified by exposure to the air: this is accomplished in the lungs, so that all the blood thus returned to the heart is immediately sent off to the lungs, from which it comes back to the heart; and this is called the *Pulmonary*[2] or *Lesser Circulation*. There are thus two sets of arteries and two sets of veins, the vessels which carry the blood from the heart to the lungs, and *vice versâ*, being called pulmonary arteries and veins respectively; although it is to be remembered that the kind of blood contained in the arteries and veins of the different sets is reversed, the pulmonary arteries containing true venous blood, and the pulmonary veins carrying back to the heart true arterial blood.

The Heart is a strong muscular bag, situated in the left side of the chest. It contains four chambers or divisions, the two in the upper end called *auricles*[3] (*d* the right auricle, and *k* the left, fig. 54), and the two in

[1] From Latin *fibra*, a thread.
[2] From Latin *pulmones*, the lungs.
[3] Latin *auricula*, diminutive of *auris*, the ear.

the lower end, *ventricles*[1] (*a* the right, and *m* the left, fig. 54). And as the most important division of the heart is into two sides, there are a right and left auricle and a right and left ventricle. Between each auricle and the ventricle on the same side, there is a valve (*c* and *l*, in fig. 54), like those in a force-pump [PHYSICS, page 17], through which the blood is forced, by the muscular contraction of the heart, from the auricle into the ventricle. The blood brought back from the body is poured, by the two veins *f* and *b*, into the right auricle; the right auricle contracting on this blood, drives it through the valve, *c*, into the right ventricle; the right ventricle now contracting, drives the blood, which cannot pass back to the auricle, because the pressure on it closes the valve, along the pulmonary artery, branches of which, *g* and *i*, go to the right and left lung respectively. The blood is brought back from the lungs by the pulmonary veins, two from each lung, *e*, *e′*, and poured into the left auricle; the contraction of the left auricle drives the blood through the valve, *l*, into the left ventricle; the left ventricle contracts, and drives the blood into the large artery, *h*, called the *aorta*,[2] because it seems to suspend the heart between the lungs.

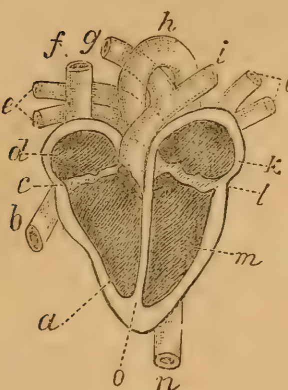


Fig. 54.

The whole of the arterial blood leaves the heart by the one large trunk of the aorta; this trunk soon divides into branches; these branches subdivide into smaller branches, and these into smaller still, until every part of the body, especially at the surface, is intersected with such a network of small arteries, that the point of a needle cannot be inserted into the flesh without wounding one or more of them, and thus drawing blood. To a certain extent, the *veins* might be said to run parallel with the arteries, branch for branch, with this difference, that they are carrying back to the heart the blood which has oozed into them through the *capillaries* from the arteries. It will easily be understood that the force of the blood in the arteries, as propelled direct from the heart, must be much greater than in the veins, in which the blood is found after it has passed through a succession of most minute tubes, where much of its velocity is lost. Accordingly, the arteries are of a much stronger structure than the veins. In consequence of the strong flow of blood through the larger arteries, they are, for the most part, placed at a distance from the surface, so as to be protected from injury; the veins, on the other hand,

[1] Latin *ventriculus*, diminutive of *venter*, the belly. [2] Greek *aortē*, from *aeirō*, to suspend.

lie, for the most part, near the surface, which renders them more liable to injury; but the consequences are less serious than in the case of the arteries, on account of the less rapid flow of blood.

The minute vessels which form the connection between the smallest branches of the arteries and the veins are called the *capillaries*,[1] from their extreme smallness. The figure (55) shews the arrangement by which the arteries and veins are connected in muscular tissue.

Fig. 55.

When the aorta leaves the left ventricle, it rises towards the neck, but soon turns downward, forming a curve called the *arch;* this trunk passes down in front of the spine, and divides into two main branches, which proceed to the legs. From the *arch* of the aorta are given off the arteries that supply the head and arms with blood: these are the two *carotid*[2] arteries (*c* and *e*, fig. 56), which ascend on either side of the neck to the head, and the two *sub-clavian* arteries, which pass beneath the clavicles to the arms (the left of these is marked *g* on fig. 56). The descending aorta while passing down gives off branch arteries to the different parts and organs—the *cœliac*[3] artery, which subdivides into three, to supply the stomach, liver, and spleen, one to each kidney, and two to the intestines. It at last divides into two branches, which supply the legs.

The veins of the body unite to form two large trunks, the *superior* or descending, and *inferior* or ascending *vena cava*,[4] which meet as they enter the right auricle of the heart, *f* and *b*, fig. 54. The descending *vena cava* is formed by the union of the veins bringing the blood back from the head, the *jugular*[5] veins, *b* and *f*, fig. 56, and those bringing it from the arms, the *sub-clavian* veins, *a* and *h*. The ascending one brings it back from the legs, the organs in the abdomen, and the trunk. The Lesser Circulation will be described under Respiration.

[1] From Latin *capilla*, a hair.

[2] From Greek *karoō*, to stupefy, because a state of torpor is brought on by stopping these arteries.

[3] From Latin *cœlia*, the belly.

[4] Latin, 'hollow vein.'

[5] From Latin *jugulum*, the hollow at the neck above the collar-bone.

Respiration.

The function of Respiration is performed in the lungs with common air. Air is composed of about 1 part of a gas called *oxygen*,[1] and 4 parts of another, *nitrogen*,[2] with an exceedingly small quantity of a third, *carbonic acid.* The change effected on air by respiration is the giving off one of these gases, oxygen, and receiving another, carbonic acid, in its place.

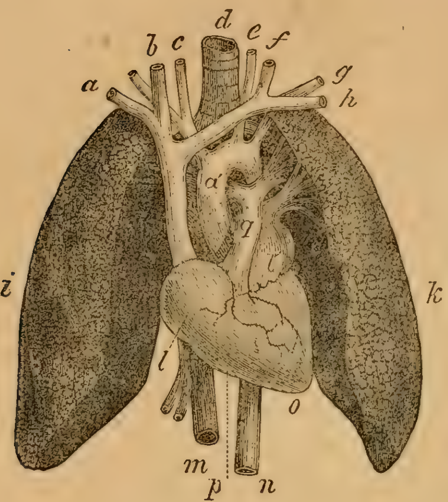


Fig. 56.

The chief difference between arterial and venous blood is, that the former contains oxygen, while the latter contains carbonic acid; and also that when the venous blood is sent from the heart to the lungs, its errand is simply to discharge this carbonic acid, and receive in exchange a supply of oxygen, with which it returns to the heart, ready to be sent off again throughout the body. It is clear then that in the lungs there must be (1) a provision for the blood coming in contact with the air; (2) an arrangement by which the blood in contact with the air shall be continually changing; and (3) an arrangement by which the air in contact with the blood shall be continually changing.

Let us consider, first, the provision for bringing the blood into contact with the air. It consists generally in having an immense extent of internal surface, covered by a complete network of minute vessels, through which the blood to be acted upon flows, separated from the air which has been inhaled only by an extremely thin membrane, so that the effect is the same as if the two were in actual contact. But how is this immense extent of surface obtained in a small compass; for the lungs are of moderate size? It is accomplished by the peculiar structure of the lungs. When the main air-tube or windpipe descends to the level of the lungs, it divides into two branches, called the *bronchi* [plural of Latin *bronchus*, the windpipe], one going to each lung (B, fig. 57). These again divide and subdivide into smaller tubes, called *bronchial* tubes, as *b*, *b*. They subdivide in this way, until at length an immense number of minute tubes is formed,

[1] From Greek *oxys*, acid, and *gennaō*, to produce.
[2] From Greek *nitron*, soda, and *gennaō*, to produce.

each of which opens into a small sac, a little wider than itself. Each of these, again, is partitioned off into a number of cells. Into the smallest of these cells the air has access, and it is on their walls that the network of capillaries is spread, in which the blood comes in contact with it. When the venous blood has returned to the heart, it is propelled from the right ventricle into the pulmonary artery. It must be remembered that this artery contains true venous blood. This artery soon divides into two, and sends a branch to each lung (*g*, *i*, fig. 54); and these ramify so as to send a minute artery along with each of the minute air-tubes, till they reach the lung-sacs already mentioned. The blood now distributes itself into capillaries on the walls of the cells and of the adjoining air-passages. The blood having in this manner come in contact with the air, and thus been rendered fit for being again sent out through the body, now passes into the first roots of the veins (so called, although they contain true arterial blood), which unite and reunite to form the four pulmonary veins that pour the blood, thus arterialised, into the left auricle of the heart, *c*, *c′*, fig. 54.

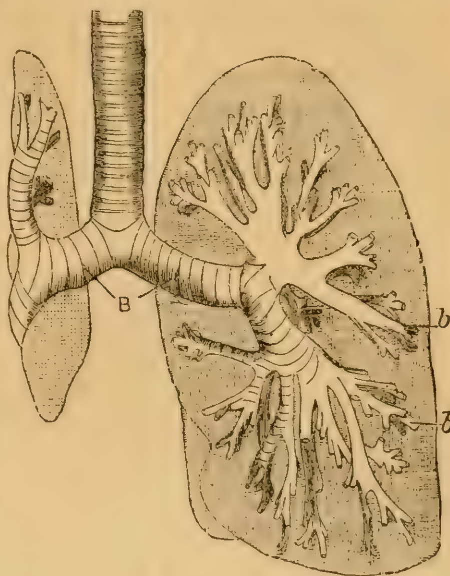


Fig. 57.

The action of the lungs is very much like what takes place on squeezing a hollow india-rubber ball in the hand, and allowing it to expand alternately. By a peculiar arrangement of the ribs, and by the contraction of the diaphragm (the floor of the chest, as it were, which, when uncontracted, rises up into the chest with a convex surface), the capacity of the chest may be very much increased. Suppose, then, the chest to be expanded; the lungs, being of a spongy nature, are also free to expand, and immediately the air rushes in through the windpipe, and fills them, just as happens when the ball is held in the open hand. But now the ribs fall, the muscles of the diaphragm relax, and the chest is contracted so as to squeeze the air out of the lungs, as happens when the hand is closed on the ball. The muscles that contract to cause these various movements act independently of the will, so that the action is kept up during sleep, which it could not be if it were voluntary.

Secretion and Excretion.

We have seen that the two functions of the blood are to deposit materials for building up and keeping in repair the different parts of the body, and to carry off the waste matter arising from the decay continually going on. The various processes by which the products of this waste are drawn off from the blood receive the general name of *secretion;*[1] and the organs for the purpose, all of which are constructed on the same principle, are called *glands.*[2] These secretions are of two kinds. One kind is merely a purification of the blood, in carrying off something which would be injurious to the system, while the other kind extracts from the blood a fluid which is intended to serve a purpose in the economy of the system. The products of the former are called *excretions,*[3] as the exhalations from the skin, urine, &c.; the products of the latter are *secretions* proper, as the saliva, gastric juice, &c. The general structure of a gland is a collection of follicles, or minute membranous bags, surrounded with a network of capillaries, from which the materials of the secretion, or the injurious substance to be excreted, are drawn. They are divided into two kinds, according to the manner in which they discharge their contents. In some cases, the secreting follicles discharge their contents separately, as the sweat glands and sebaceous glands of the skin. The work of secretion is really performed by cells or exceedingly minute bags, lining the follicles; and another form of discharge is when these cells, without being contained in follicles into which they discharge the fluid secreted, lie on the surface of a membrane, and discharge their contents upon it directly, as in the case of the mucous membranes.

In the more complicated secreting organs, such as the liver or kidneys, one or more tubes which carry off the secretion ramify in the organ into very minute branches; and at the point of each of the smallest twigs is a follicle, lined with cells, which discharge their contents into the follicles, to be carried off by the tubes.

The LIVER is the organ which secretes the bile, and is a body of a dark-brown colour, divided into two lobes, and lying opposite the stomach, on the right side. Part of the bile is sent direct from the liver to the intestine, but there is a reserve kept in the gall-bladder, a little bag attached to it. The bile is drawn from the venous blood returning from the abdomen, which is made to pass through the liver in its passage to the heart.

The KIDNEYS lie in the lumbar region, in front of the backbone, one on each side, and are imbedded in fat. The function of this organ is to

[1] From Latin *secerno*, to put aside or separate. [2] Latin *glans*, an acorn, a gland.
[3] From Latin *excerno*, to sift.

excrete the urine, in which are carried off, dissolved in a large quantity of water, several substances which would act as poisons if left in the system.

Other secreting organs are the *pancreas*, a large oblong gland behind the stomach, which secretes the *pancreatic* juice, described under Digestion; the *spleen*, situated near the upper left-hand corner of the stomach, the function of which seems to be to act as a storehouse of nutritive material, which can be taken advantage of by the circulation, in certain emergencies of the system; and the *mammary*[1] *glands* or breasts (in women), which secrete milk for the nourishment of infants.

The Nervous System.

The functions of organic life are merely secondary and subservient to the higher or animal life. All the arrangements of the organism of the body, considered as a complete structure, are adapted to connect the Spirit of which it is the tenement with other beings and things around it—to receive sensations, to feel, to think, to will, and to act under the guidance of the mind or of instinct. For the purpose of carrying on the functions of this higher life of the human being, we find what might be called a complete telegraphic system. There is a *head*-office, to which telegraphic messages are sent from all parts of the body, telling what is going on, and asking for instructions as to what ought to be done in the circumstances; and forthwith messages are sent back with the required instructions. When one places the hand on something burning, a message immediately goes off to the head-office from the hand, that it is being burned, and back comes a message to the muscles of the arm to withdraw the hand from the dangerous spot; and it is done. Or, again, suppose a man to be crossing a street, and a vehicle to come up behind him. First, there goes a message from the ears to the head-office that there is a sound of wheels behind. At once a message is sent off to the muscles of the neck to turn the head, that the eyes may be able to report how matters stand. Probably the eyes send in a message to the effect that a cab is close behind. When this is taken into consideration in the head-office, the conclusion is come to, that it would be advisable to have the body removed out of the way as quickly as possible; and accordingly, a message is at once sent to the muscles of the legs, telling them to be active; and the visible effect is that the man jumps out of the way. This is no fanciful description; but a process similar to that here described is what actually takes place in most actions, although these may be done in an instant. Now, this telegraphic system is the *nervous system;* the head-office is the *brain;* the telegraph *wires* are an immense

[1] From Latin *mamma*, the breast.

number of nerves, or nervous fibres, spread over the surface of the body, being especially abundant in the organs of sense.

What is the nature of the connection that exists between the mind and the action of the brain, no one has yet been able to tell; we only know that there is a connection. Nor can the nature of nervous influence be explained. The nearest approach to an explanation that can be given, is to say that it acts like electricity; and, indeed, the similarity between the action of the nervous system and that of the electric telegraph is greater than at first might be supposed. When treating of the muscles, we saw that they have the power of contracting. The principal agent in producing contraction of the muscles is the stimulus conveyed to them through the nerves.

The substance of which the nervous system is composed is of two distinct kinds, called, from their appearance, *white* and *gray* matter. The white matter consists of straight fibres, lying side by side, and bound into bundles; these bundles are again bound together into larger bundles; and in this way are formed the nervous *trunks* which are spread throughout the body, and which are entirely formed of this white or fibrous matter. The gray matter is found, to a great extent, in the *ganglia*,[1] or nerve-*centres*, which are masses of nerve-matter occurring at intervals on the trunks. This gray matter is not of a fibrous texture, like the white, but consists of cells; and it seems, that in some way or other, the nerve-fibres of the trunks communicate with the cells of the gray matter in the ganglia. The office of the nerve-fibres in the trunks is to convey the influence of something going on in one part of the system to another part. These influences, as has been indicated, are sent in two directions —the impressions made on the sensitive parts of the body are conveyed to the nerve-centres, and give rise to what are called *sensations;* and when these sensations cause certain emotions, or an exercise of the will, an influence is sent outward to the muscles, which are thereby excited to contraction. And it has been proved that these different messages are conveyed by two different sets of fibres: those which carry an influence *to* the nerve-centres being called *sensitive* or *afferent;*[2] and those which carry an influence *from* these to the muscles, *motor* (because for the most part giving rise to *motion*) or *efferent.*[3]

The nervous system consists of two parts—a central part, called the *cerebro-spinal* axis, which consists of the *brain* and the *spinal cord,* lodged within the skull and the vertebral column; and an outside part, consisting of nervous trunks proceeding from the central part, and distributed to all parts of the body. The brain is composed of a number of ganglionic masses, each of which is at the head of a special department;

[1] Plural of *ganglion*, Greek, a knot.
[2] From Latin *ad*, to, and *fero*, to bring.
[3] From Latin *ex*, out from, and *fero*, to bring.

thus, each of the nerves of special sense—for example, taste, smell, &c.—has its own proper centre. The most prominent part of the brain is the *cerebrum*,[1] or, as it is also called, the *cerebral hemispheres* (because it is divided into two by a deep fissure from front to back), which, on the outside, presents the appearance of a piece of cloth crushed together in irregular folds. On the outside is a coating of gray matter, while in the inside is white matter. Behind and beneath the cerebrum is the *cerebellum*, or little brain, which is also divided into two hemispheres, and which is specially charged with the regulation of movements. From the brain, and through openings in the skull, proceed a number of nerves to the different organs about the face; and as these organs are for the most part double, the nerves go in pairs; thus, a pair of *olfactory*,[2] or smelling nerves, go to the nose, a pair of *optic*,[3] or seeing nerves, go to the eyes, and a pair of *auditory*,[4] or hearing nerves, to the ears. Besides these pairs, there are nerves to the organs of taste, and a number of others both afferent and efferent.

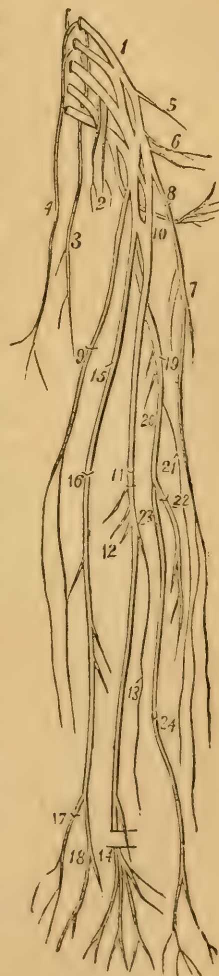


Fig. 58.

From the base of the cerebellum, the spinal cord passes down through the middle of the series of vertebræ forming the spine, sending out nerves to the trunk and limbs; and its principal function is to connect these nerves with the brain, although it has also influence of its own not dependent on the brain. The nerves springing from the spinal cord are all in pairs, arising between each pair of vertebræ, one on each side. The manner in which nerves are supplied to the extremities is through what is called a *plexus*,[5] or network. Several nerves spring from the spinal cord, and proceed together for some distance without meeting; they then divide, and branches from different nerves unite to form new nerves, and these again divide, and interchange fibres; and the nerves thus formed proceed to the extremity, as seen in fig. 58, which represents the nerves of one of the arms.

Besides the system of nerves just described, there is another set of nerves and ganglia in the body. There is a chain of ganglia, connected by nervous cords running down in front of the spine, which sends off nerves to the viscera and

[1] From Greek *kara*, the head.
[2] From Latin *olfactus*, the sense of smell.
[3] From Greek *optos*, seen.
[4] From Latin *audio*, to hear.
[5] From Latin *plecto*, *plexum*, to twist or knit.

blood-vessels in the chest, abdomen, and pelvis. This system of ganglia, which seems to regulate, almost independently of the will, the processes of digestion, circulation, and respiration, its influence being little, if at all, dependent on the brain, has therefore been called the nervous system of organic life, or the *sympathetic system.*

When an impression is made on any of the nerves of the body, it carries this impression to the brain, and causes a *sensation.* The impressions made on the nerves are not all the same, however; the different kinds of sensations thus caused in the brain are classed into those of Touch, Taste, Smell, Hearing, and Sight.

Touch.

The special seat of the sense of touch is the surface of the skin. The epidermis, it will be remembered, is not sensitive; the parts really sensitive are the *papillæ,* on the outside of the *cutis,* or true skin. It is to these papillæ that the nerves are distributed on which the impressions are made by the various objects touched, and by which these impressions are conveyed to the brain. They are largest and most numerous on the palms of the hands and the soles of the feet; on the back and outside of the limbs they are much less numerous. They are small elevations, usually conical or club-shaped. Where the sense is acute, however, they have several points, from which they are called *compound* papillæ. The epidermis is also particularly thin on those parts where the sense of touch is acute, as, for example, on the tips of the fingers and lips. The papillæ are arranged in rows, and it is these rows that cause the fine ridges in the epidermis seen on the palm and fingers.

The simplest idea conveyed to our minds on touching any object is *resistance;* by the degrees of resistance we meet on touching a body, we judge whether it be hard or soft; and on moving the fingers over the surface, the impression made on the papillæ informs us whether it be smooth or rough. Were it not for our faculty of moving the hands over bodies, indeed, the sense of touch would have been of far less value than it is; for without that faculty we could not have formed our ideas of form and size.

Taste.

The seat of the sense of taste is principally, though not exclusively, on the surface of the tongue, and the arrangement is very similar to that described for Touch. The nerves of taste, like those of touch, are distributed to papillæ, in the outer membrane of the tongue. One remarkable difference in the arrangement of the papillæ of the tongue is that, instead of being concealed in its skin, they project and form the roughness of the tongue, being covered of course by the outer coat. There are

on the tongue both simple and compound *papillæ*, the former very much like those in the skin, the latter of various forms. The sense of taste is very much assisted by that of Smell, as is seen in the case of aromatic substances, the taste of which is much weaker when the nostrils are closed than when they are open. Other substances, called *pungent*, such as pepper, mustard, &c., when tasted, produce a sharp, pricking sort of sensation, which is also produced on the skin—that is, by the sense of touch—if the same substances be applied to it strongly enough. Touch and taste are thus very closely connected. It may be remarked that the sense of true touch is very acute on the tip of the tongue.

It is always necessary that the tongue be moist in order to taste anything ; and it seems, too, to be a condition in substances having taste that they be soluble in water, as bodies that cannot be dissolved in water are quite tasteless.

Smell.

The seat of the sense of smell is in the cavities of the nose into which the nostrils open, and which open behind into the pharynx, or entrance to the windpipe, above the soft palate. The two cavities are separated from each other by a vertical partition, principally composed of cartilage, of which, indeed, the greater part of the framework of the nose is composed. The walls of these cavities are lined with a thick, velvety membrane, over which the olfactory nerves are distributed. It will be remembered that the outer walls are partly formed by the 'turbinated' bones (p. 45), which form three projections on each side, with hollows between. The object of this arrangement is to increase the surface over which the membrane is spread, as it is on this to a great extent that the acuteness of the sense depends. The membrane is kept continually moist by mucus, to which the particles of any substance smelt attach themselves when carried into the nostrils by the air, and thus, coming in contact with the extremities of the olfactory nerves, produce the impression which gives rise to the sensation of smell. It is on the roof of the cavity that the sense is most acute ; and the effect of *snuffing up* the air is to throw the particles on that part, so as to enable us to detect odours that might otherwise escape us ; although most people are unconscious of the object of this action.

Hearing.

The ear, the organ of hearing, is more complicated than any of the organs of the senses yet described. It consists of three parts—the *external*, *middle*, and *internal* ears, the last two lying in cavities in the temporal bones. The *external* ear consists of the fleshy part seen on each side of

the head, which ordinarily receives the name of ear for itself, and of the passage seen entering the head. This passage is completely closed on the inside by a membrane called the *membrane of the drum* of the ear, and behind this is the *middle* ear. The latter is a cavity filled with air, received through a tube communicating with the nose, and across which there stretches a chain of curiously shaped little bones. These bones form the communication between the membrane of the drum and one of the membranes covering the two openings into the internal ear, and their use seems to be to communicate the sound-vibrations with greater intensity than if they had been communicated direct to the inner membrane. The *internal* ear consists of three parts—the *vestibule*, the *semicircular canals*, and the *cochlea* [Latin, 'the shell of a snail']. The *vestibule* is the middle part V, and communicates with the *middle* ear by an opening covered with a membrane, to which the end of the bony chain mentioned above is attached; the other two parts are extensions of this cavity (and open into it, as into a *hall;* hence its name) chiefly for the purpose of giving a greater extent of surface for the membrane in which the fibres of the auditory nerve are distributed. The *semicircular canals* are three passages, S, in the bone, all lined with the same membrane as the vestibule. The *cochlea,* C, is a spiral canal, very like the inside of a snail-shell, and also lined with the membrane of the vestibule. The passage is divided into two by a partition running through it lengthwise. The two passages thus formed only communicate with each other at the inner end; at the entrance of the spiral, the one passage opens into the vestibule, the other into the middle ear, the latter opening being closed with a membrane. All these cavities are completely filled with a fluid, which is made to vibrate when the vibrations of the air which strike on the membrane of the drum are communicated, through the chain of bones in the middle ear, to the membrane covering the entrance to the vestibule. These vibrations act on the fibres of the auditory nerve distributed over the membrane lining the cavities; and the impressions being communicated to the brain, produce the sensation of sound.

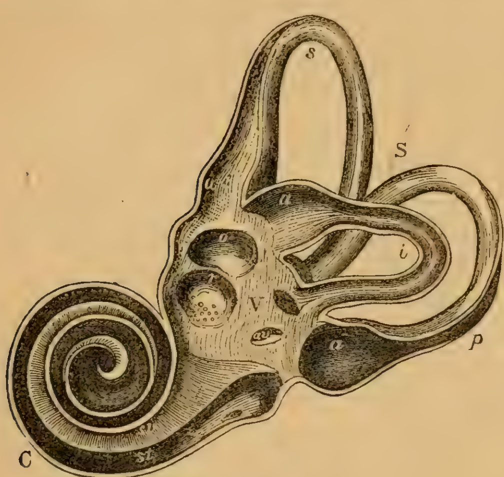


Fig. 59.

Sight.

The organ of sight is the Eye, which is a spherical body, and composed of several protective coats on the outside, and of a delicate optical instrument in the inside. The outer wall of the eyeball is composed of three coats. The outermost coat, called the *sclerotic*,[1] 1, fig. 60, is a strong, tough, fibrous membrane, the use of which is to protect the parts inside. It does not cover the whole of the eye; the front of the eye, or that part which is visible, is covered with a transparent, *horny* or cartilaginous plate, called the *cornea*,[2] 2, which fits into the edge of the *sclerotic*, almost exactly in the way the glass of a watch fits into the case. The

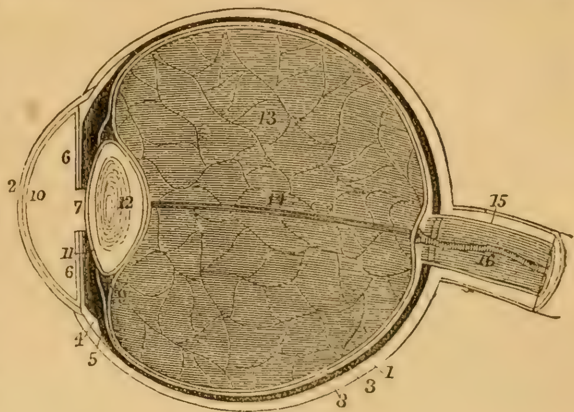


Fig. 60.

cornea, as may be seen from the figure, bulges out a little beyond the line of the sclerotic, or is rather more convex. The second coat is the *choroid*,[3] 3, a more delicate structure than the last, consisting almost entirely of blood-vessels and nerves. It is of a very dark colour; and it is this dark coat, seen through the narrow opening in the centre of the iris, which causes the round black spot to appear in the centre of the eye. Like the *sclerotic*, this coat also gives place to another in front of the eye; instead of the *choroid*, in front is the *iris*,[4] 6, 6, a coloured membrane, which hangs down behind the *cornea*. The use of the *iris* is to act as a curtain, to regulate the amount of light that is to be admitted into the eye; for it is contractile, and can thus diminish the size of the little hole, or *pupil*,[5] 7, when the light is too strong, as may be observed in the eye of any one looking at a strong light. The third coat is the *retina*,[6] 8, so called because it is a complete *network* of nerve-fibres from the optic nerve, 15, 16, extending all round the back part of the eye, being deficient towards the front.

In the interior of the eye, we come first to the *aqueous humour*,[7] which is a fluid little else than pure water, filling the *anterior* chamber

[1] From Greek *skleros*, hard, stiff.
[2] From Latin *cornu*, a horn.
[3] From Greek *chōrion*, any skin.
[4] From Greek *iris*, a rainbow.
[5] From Latin *pupillus*, a child; because, on looking into it, one sees one's own image reflected exceedingly small.
[6] From Latin *rete*, a net.
[7] From Latin *aqua*, water; *humour* is any fluid or moisture, from Latin *humeo*, to be moist.

of the eye, 10, and also the *posterior*, 11, or that part behind the iris and in front of the crystalline lens, 12. The *crystalline lens* is a humour like a thick, transparent jelly, enclosed in a transparent bag, and attached to the *choroid*, so as to keep it in its place immediately behind the pupil. As a whole, it forms a double-convex lens (OPTICS, p. 28), but with the posterior surface more convex than the anterior. Filling the whole cavity behind the crystalline lens is the *vitreous*[1] humour, a *glassy*, transparent fluid, of the consistence of thin jelly. The optic nerve enters immediately behind the eye, 2 (fig. 61), and is spread out into the retina.

All the movements of the eye are performed by six muscles: four attached directly opposite to each other, above, below, and at each side, 9, 13, 10, and 11—12; and two oblique muscles, which turn the eyes towards any of the corners. The act of thus pulling the eye *forward* is effected by these oblique muscles, 7, 8, passing through pulleys, as 6, in fig. 61. A very important appendage of the eye is the eyelid, which serves to protect the eye when closed, and also to sweep off any dust or impurity, by coming down over the eye, which it can do so rapidly as not to interfere with the sight. And in order to prevent a disagreeable rubbing in doing this, there is a fluid known as tears (when in more than an ordinary quantity), being continually poured on the upper part of the eye from the *lachrymal*[2] gland. This fluid is carried off (except when so abundant as to overflow the eyes) by a little canal which communicates with the nose. The entrance to it may be seen on the inner edge of the under eyelid, almost in the inner corner.

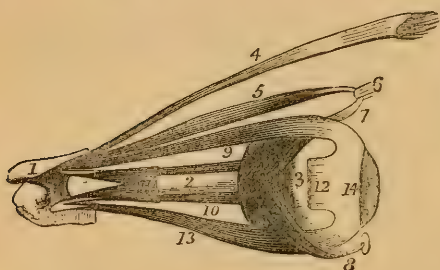


Fig. 61.

When diverging (OPTICS, p. 26) rays of light, from any point, fall on the eye, those that fall on the opaque sclerotic, or *white* part of the eye, are lost. The cornea being transparent, the rays that fall on it pass on; then those that fall on the coloured iris are absorbed, while some pass through the pupil. After traversing the aqueous humour, which probably has little effect in changing their direction, the rays strike on the crystalline lens; the latter, on account of its convexity and comparative density, has strong refracting power, and after passing through it and the vitreous humour (the function of which is chiefly to support the retina), the rays are drawn to a point, or *focus*, on the retina. When rays from all the points of a body are thus thrown on the retina, the impression conveyed to the brain is a complete image of the object.

[1] From Latin *vitrum*, glass. [2] From Latin *lachryma*, a tear.

ZOOLOGY.

Introduction.

Zoology—from the Greek *zōon*, an animal, and *logos*, a discourse—is the branch of Natural History which treats of animals. In the largest sense of which the term is capable, it may be held to include man as part of its subject; but the term is not in general thus employed. Yet man has much in common with the lower animals; and a knowledge of human anatomy and physiology is necessary for the successful study of the structure of animals and the phenomena which life displays in them.

Of the three kingdoms of nature two are classed together as *organic*—the animal and the vegetable, the mineral being set apart as *inorganic*. Both plants and animals consist entirely of organs, and internal movements are kept up by fluids in cells and vessels, during the whole existence of the individual. It is not easy to define the term *animal*, familiar as is the idea conveyed by it. If we say that an animal is a creature having life, our definition is not perfect, for plants also have a kind of life, although we readily note a great difference between it and that which belongs to animals. When we study the lowest forms that nature presents to us in both kingdoms, it is sometimes difficult to determine to which kingdom a particular kind of creature belongs, although it is probable that our difficulty may be owing to our imperfect acquaintance with the subjects of our study, for no such difficulty is felt as to any of the higher kinds, the phenomena of whose life are better known to us. Perhaps the power of voluntary motion ought to be regarded as the true distinguishing characteristic of animals. When we think of animal life, we always associate with it the idea of *mind*—of a *will*, and *feeling*, or a capacity of pleasure and pain. To plants we do not ascribe will or feeling, even in the lowest degree. We associate no such idea even with the phenomena of irritability in the sensitive plants, or in flowers expanding under the sunshine, and turning toward the sun. If there be another distinction universally subsisting between animals and plants, it is that animals feed only on vegetable or animal substances; whereas the whole nutriment

of plants consists of inorganic substances, decomposition necessarily taking place before any organic substance can afford food for a plant.

Other peculiar characteristics of animals readily present themselves to the mind, but are not universal like these. Thus, animals are generally endowed with the power of locomotion, but some are destitute of it during the greater part of their existence. The animals with which we are most familiar all possess the senses of sight, hearing, &c.; but there are multitudes of creatures low in the scale of animal life which are destitute of these, having no brain nor manifest nervous system, and no organs of special sense, although it seems that they are generally sensible of the contact of external objects, and they manifest an avidity for food. Animals generally have a mouth and a stomach—indeed, some of the lower kinds may be described as consisting of little more, and very much resembling a bag, the mouth of which is capable of being opened and shut —but there are some which have neither mouth nor stomach, properly so called, and imbibe their nourishment through their skin at all parts of their body. The animalcules of the genus *Amœba*[1] or *Proteus*[2] resemble small masses of jelly, which seem to flow rather than crawl or glide over objects. For locomotion they protrude a portion of the substance of the body in any direction, the remainder following it. When one of them finds a particle of matter suitable for food, it envelops it, the body opening at any point to receive it, closing round it again, and retaining it till all that is capable of assimilation is extracted from it, and absorbed into the living jelly.

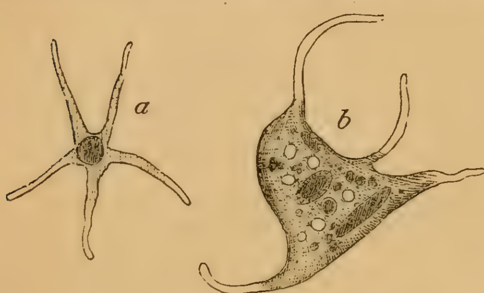


Fig. 62.—Amœba radiosa.
a, young Amœba; *b*, another specimen.

In all probability the largest animals that exist are certain species of whale; but we are acquainted with many animals so small, that their existence can only be discovered by the aid of a powerful microscope, myriads inhabiting a single drop of water, whilst there may be others still more minute, which no optical instrument yet invented enables us to discern. 'Take any drop of water from the stagnant pools around us,' says Professor Rymer Jones, 'from our rivers, from our lakes, or from the vast ocean itself, and place it under the microscope; you will find therein countless living beings moving in all directions with considerable

1 Greek, 'vicissitude.'
2 From *Proteus*, a being of the Homeric mythology, who sought to elude observation by continually changing his shape.

swiftness, apparently gifted with sagacity, for they readily elude each other in the active dance they keep up. . . . . Increase the power of your glasses, and you will soon perceive, inhabiting the same drop, other animals, compared to which the former were elephantine in their dimensions, equally vivacious and equally gifted. Exhaust the art of the optician, strain your eyes to the utmost, until the aching sense refuses to perceive the little quivering movement that reveals the presence of life, and you will find that you have not exhausted nature.'

Classification of Animals.

The number of different kinds of animals is very great, vastly exceeding that of plants; and the diversities amongst them are very wide, not merely in size, but in structure and habits. Classification, therefore, is absolutely necessary, in order to obtain an intelligent view of the animal kingdom; but there are some groups which at once present themselves to the observer as distinctly marked, and which therefore have been universally recognised from the earliest times. Such is the great group of Birds, or that of Fishes; although observation more exact was necessary to exclude bats from the former, and whales from the latter. The greater group of Vertebrate Animals, in which both Birds and Fishes are included, is also so natural that it must have a distinct place in every system of classification. We cannot here give an account of the various systems of classification which have been proposed. That of Cuvier has been generally received since the beginning of the present century. Cuvier regarded the animal kingdom as consisting of four great divisions —*Vertebrata*, *Mollusca*, *Articulata*, and *Radiata*. The first division, *Vertebrata* or Vertebrate Animals, consists of animals having an internal bony skeleton, the principal part of which is a back-bone or vertebral column, composed of short joints, to which all the other parts are attached. All the highest classes of animals belong to this division—Mammals, Birds, Reptiles, and Fishes. Man himself, considered as to his corporeal frame, belongs to it. All the other divisions of the animal kingdom are united under the common designation of *Invertebrata* or Invertebrate Animals; but they differ far more widely from each other than the classes of vertebrate animals, and are therefore regarded by Cuvier as forming three great groups, each equal in rank with the Vertebrata. His second division, *Mollusca*,[1] consists of animals which have no skeleton, external or internal. Their bodies are always soft and covered with a skin, and often protected by an external shell, which they secrete. Snails, slugs, oysters, mussels, cockles, and most of the other creatures popularly called *shell-fish*, belong to this division. Cuvier's third division, *Articulata*[2] or Articulated

[1] From Latin *molluscus*, soft. [2] From Latin *articulatus*, jointed.

Animals, contains animals which, however great their other differences, have this character in common, that they are composed of segments articulated or jointed together in a line. Insects; Crustaceans, as crabs and lobsters; *Arachnids*, as spiders and mites; and *Annelids*, as leeches and worms, belong to this division. These three great divisions continue to be recognised as Cuvier established them. Not so, however, his last great primary division, *Radiata*[1] or Radiated Animals, which takes its name from the arrangement of the organs of sense and motion in rays around a centre. Cuvier placed in this division many groups of animals in which no such arrangement is to be discerned, and which differ very widely from the true Radiata. With regard to these—the lowest tribes of animals—the progress of discovery has recently been very great, consequently a modification of Cuvier's system has become necessary, and new groups have been constituted.

Protozoa.

The very lowest tribes of animals, those of most simple organisation, are now generally regarded as a distinct primary division of the animal kingdom, to which the name *Protozoa*[2] is given. With the exception of sponges, almost all the Protozoa are minute, and most of them are microscopic. Except a few that are found in the bodies of other animals, they all live in water. In general, their bodies consist simply of a mass of gelatinous matter. They have no nervous system, and therefore no organs of special sense; and none of them, except one group, have a mouth or an intestinal canal.

Rhizopoda.—Among the lowest of the Protozoa, those most remarkable for the simplicity of their organisation, or want of distinct organs, are the *Rhizopoda*,[3] a class particularly important on account of their universal diffusion, the multitudes in which they exist, and the great variety of kinds. The Amœba, already mentioned, may be regarded as a type of this class. All of them have, like it, the power of throwing out in any direction *processes* of the gelatinous substance of which they are composed, which are sometimes broad and lobe-like, but in other species are slender and of great length. The most interesting of the Rhizopoda are those which constitute the group called *Foraminifera*,[4] which are covered with a shell, and to which we owe the countless multitudes of minute fossil-shells forming great part of chalk and some other rocks, whilst the shells of still existing species abound in the sand of our sea-shores. These creatures are merely little particles of a kind of jelly; yet the shells which they produce are of the most exquisite beauty, and exhibit a

1 From Latin *radius*, a ray. 2 From Greek *prōtos*, first, and *zōon*, an animal.
3 From Greek *rhizon*, a root, and *pous*, *podos*, a foot.
4 From Latin *foramen*, a pore, and *fero*, to bear.

wonderful regularity of structure. Their forms are extremely various, the species being very numerous. Some are simple, and of these some

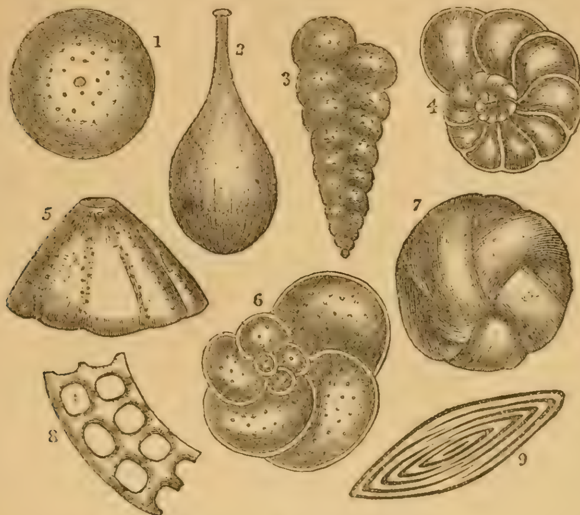


Fig. 63.—Foraminifera:
1—7, Various species; 8, Part of two chambers of one; 9, Vertical Section of a fossil species.

are orbicular, others curiously flask-shaped; but many are chambered, and thus composed of parts variously arranged, sometimes in a straight line, sometimes spirally, but always regularly. These chambered shells seem to be formed in consequence of what is called *gemmation*,[1] or the growth of new individuals from an existing animal, as of buds on a tree. The shells of all the Foraminifera are pierced with numerous pores, through which long delicate *processes*—extensions of the soft body of the animal—are protruded when occasion requires.

Sponges.—Sponges, the only Protozoa that attain a large size—which they do, however, merely in virtue of the formation of aggregate or compound animals by gemmation—are perhaps the lowest of all creatures in the scale of animal life. The movements of a living sponge suggest the idea of animal rather than of vegetable life, but its form and manner of growth are plant-like. It is fixed by its base like a sea-weed; it seems utterly insensible to touch; it may even be pinched with a forceps, or torn to pieces, or bored with a hot iron, without a symptom of suffering. No wonder, therefore, that sponges should long have been regarded as plants. When the life-history of a sponge, however, is considered, its animal nature at once becomes certain. A sponge in its mature state generally consists of a horny fibrous framework, which is all we see in the

[1] From Latin, *gemma*, a bud.

sponges of commerce, and which may be regarded as the skeleton of the animal: sometimes the skeleton is formed of calcareous or siliceous needles, which are beautiful microscopic objects, admirably grouped and arranged. In a living sponge, the whole framework is covered and its cavities filled with a gelatinous or glairy substance, which is the really living part. A mature sponge is, in fact, composed of a vast number of creatures somewhat resembling Amœbæ, aggregated together, and having their framework in common. A young sponge, as it comes forth from the egg of its parent, has the faculty of moving about in the water by shooting out *processes* of its soft body, like the Rhizopoda. By-and-by, it attaches itself to some rock or other fixed substance, and becomes itself immovably fixed, ceasing to possess the power of locomotion. Its plant-like framework begins to grow, and the animal mass rapidly increases. Every one knows that the surface of a piece of sponge is perforated with a multitude of very small openings, amongst which are a number of larger ones, and that the inside is full of little cavities. In the live sponge there are currents of water continually flowing in at all the smaller openings, which are carried through the whole mass, conveying to every part of it the particles of matter which serve for nourishment, and also the air for its respiration. These currents of water are collected into canals, and pass out by the larger openings, carrying with them all the refuse, and many sponge buds, as they may be termed, which become detached from the parent, and go forth to found new colonies, as well as the eggs which are occasionally produced.

Infusoria.—The *Infusoria* are a class of Protozoa of somewhat higher organisation than the Rhizopods and Sponges. They have a mouth and a gullet, which, however, does not convey the food into a stomach, but into the general internal cavity of the body. Like the other Protozoa, they are composed of a gelatinous substance, but it is covered with a skin, and does not exhibit that variability of form so remarkable in the Rhizopoda. Many of them are also furnished with hair-like organs, called *cilia*,[1] the motion of which carries them with great rapidity through the fluid in which they live, and also creates currents to bring food to the mouth. The Infusoria often multiply by spontaneous division, and each half speedily acquires a mouth and cilia for itself. The multiplication of some Infusoria in this way is extremely rapid. One species has been observed to undergo division every twenty-four hours, from which would result 16,384 individuals in a fortnight, and 268,435,456 in four weeks. It is from the fact of their occurring in all infusions of animal and vegetable substances which stand for a short time exposed to the air, that the Infusoria receive their name. There are very many different kinds, exhibiting great variety of form and structure. Their multitudes are so

[1] From Latin *cilium*, an eyelash.

great, that leagues of the ocean are sometimes tinged with them, although they are individually so minute that the number contained in a single cup of water may exceed the whole human population of the globe.

Cœlenterata.

Superior in organisation to the Protozoa, and generally regarded as ranking next above them, are the groups which unitedly receive the name of *Cœlenterata*.[1] A great similarity of structure appears in all the Cœlenterata. Their bodies are composed of two layers, one of which forms the external covering, and the other lines the internal cavities. The body is generally soft, and has a digestive cavity with one opening or mouth, which is generally surrounded by a fringe or circle of arm-like *tentacles*[2] or *feelers*, employed to capture prey and convey it to the mouth—the first organs of prehension that have come under our notice in this survey of the animal kingdom. The mouth is not furnished with jaws, teeth, nor any organ of mastication, but the food which it receives is conveyed

Fig. 64.—Campanularia dichotoma, magnified.

Fig. 65.—Plumularia falcata (natural size):
a, the ovarian vesicle and four of the polype-cells of *P. falcata*, magnified.

at once by a short canal into the digestive cavity. The Cœlenterata, however, are provided with other organs besides their tentacles for the purpose of obtaining prey. Deadly poisoned lances, long and slender, lie coiled

[1] From Greek *coilos*, hollow, and *enteron*, an intestine.
[2] From Latin *tento*, to feel.

up in cells around their tentacles, or in some part of the outer layer of the body, and are darted out to wound and sting to death any worm or other small animal that may come within their reach. The Cœlenterata are all aquatic animals, most of them marine. Some are attached by a base to a rock or other fixed object, the mouth being at the opposite extremity, while others swim freely in the water. Many are *compound* animals, increasing by gemmation, the common stem branching in very various and beautiful forms in the different species, and the individuals—if they may be so termed—which compose the community, being arranged with as perfect regularity as the flowers of any plant. From their plant-like appearance, many of them have been called *Zoophytes*,[1] and some have, for a similar reason, received the popular names of Animal-flowers and Sea-anemones. From the circle of tentacles surrounding the mouth, many are termed *polypes* or *polypi*.[2] The common stem of many of the compound species is protected by a horny or calcareous secretion, which gives it strength to resist the action of waves and currents, and having a minute cup or cell for each polype to retire into upon the approach of danger. Coral reefs are formed by the calcareous secretions of polypes, which remain as stony masses after the polypes have died, and afford a foundation on which other polypes may proceed to build. Great tracts of country and many whole islands of the Pacific Ocean consist of coral rock, the work of these tiny and apparently insignificant animals.

The Hydra.—The polypes of the genus *Hydra* may be regarded as the type of one of the chief groups of Cœlenterata. They are inhabitants of fresh water, and may often be found adhering to stones, submerged leaves, or twigs. When not looking out for its prey, the Hydra has the appearance of a small gelatinous button; when active, it extends itself into the form of a hollow cylinder, less than an inch long, with a circle of slender tentacles round the mouth (*a*, fig. 66, represents a Hydra in this state). The body may be described as consisting merely of an outside skin and the lining of the cavity that traverses its whole length from the mouth. This cavity is all the digestive apparatus the Hydra has; indeed, its structure is so simple, that it may be turned outside in without being destroyed, for the outer layer just adapts itself to do the duty of the inner, and the inner to do that of the outer.

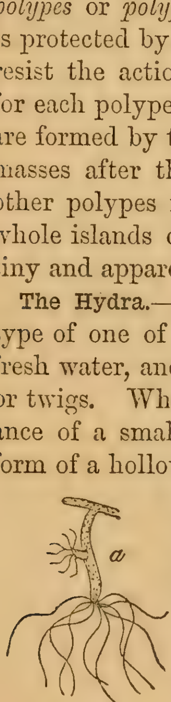


Fig. 66.

It will be noticed that on the side of the Hydra in the figure, there is a little one growing. It is thus that the young are produced by gemmation. A wart-like knob begins to grow; and as it grows it becomes more and more like the parent animal, till at last it becomes contracted where it is

[1] From Greek *zōon*, an animal, and *phyton*, a plant.
[2] From Greek *polys*, many, and *pous*, a foot.

joined to the parent, and finally is cut off altogether, and commences an independent existence.

The Actinia.—The *Actinia*, or Sea-anemone, may be taken as a type of another chief group of Cœlenterata. There are many species of Actinia, and some of them are common on the British shores. It is in tropical seas, however, that they are most numerous, and attain the greatest size and beauty. An Actinia consists of a cylindrical body, the lower end forming a disc by which the animal is generally attached to a rock or other object, whilst at the other end is the mouth surrounded by numerous tentacles arranged in circles, like the petals of a flower. Many of the Actiniæ vie with the finest flowers in the delicacy and brilliancy of their colours. When left dry by the receding tide, or when rudely touched, they contract into a jelly-like mass. In this condition, the most common British species must be familiar to every one who has gathered periwinkles, or searched for shells on a rocky shore. It is far from being the most beautiful of our British Actiniæ, but it is one of those most easily kept in the aquarium. It is capable of subsisting for a considerable time without supplies of food, but is very voracious, and readily accepts morsels of almost any animal substance. When food comes within reach of the tentacles, those nearest to it lay hold of it, and convey it not only into the mouth, but into the stomach, not letting go till it is fairly lodged there. Many animals seem to have an instinctive horror of the tentacles of the sea-anemone. The hermit crab instantly flees out of its shell, if the shell is caught by them; as any one may readily observe for himself, who, having found a sea-anemone of good size in a rock-pool, brings a hermit crab cautiously near to it.

Radiata.

The characters upon which Cuvier founded the primary division of the animal kingdom which he called *Radiata*, or Radiated Animals, may be seen in their greatest perfection in star-fishes. These creatures belong to a class to which the name of *Echinodermata*[1] is given from their generally rough or spiny integument. They are much higher in organisation than any of the groups hitherto noticed; they have a distinct digestive system, and a distinct vascular system, although for the former many of them have only a single orifice. A circular and radiating nervous system has been observed in many. They are especially distinguished from all the *Protozoa* and *Cœlenterata* by their well-organised skin, which is often strengthened by calcareous plates, and sometimes has the additional protection of numerous long spines, as in Sea-urchins; and are further characterised by their *water-vascular system*, or apparatus for *water-circulation*, a peculiarity of the radiate animals. This water-vascular

[1] From Greek *echinos*, a hedgehog, and *derma*, skin.

system is particularly connected with the organs of locomotion, which are different from those of all other animals, and are called *ambulacra*[1] (*a, a, a,* in fig. 67). They are fleshy and tubular, more or less elongated, and terminated by suckers. Their number is often very great. They pass through orifices in the external integument of the animal, and are generally arranged in rows. The movements of the ambulacra are accomplished in a very remarkable manner. Each of these organs has at its base a vesicle (*b, b,* in fig. 67), supplied with a watery fluid from a tube which springs from a special secreting organ (*c* in fig. 67). By the contraction of the vesicles, the fluid is forced into the ambulacra, distending them to their utmost extent; whilst on their being contracted by another set of muscles, it returns into the vesicles. A star-fish, or even a sea-urchin, can climb a perpendicular rock or the side of a glass vessel by means of this apparatus. The mouths of the Echinodermata are variously furnished with masticating organs; that of the Sea-urchins has generally five flat calcareous teeth, moved by a very complex apparatus of muscles and bony sockets, which acts as a very powerful mill for grinding down food.

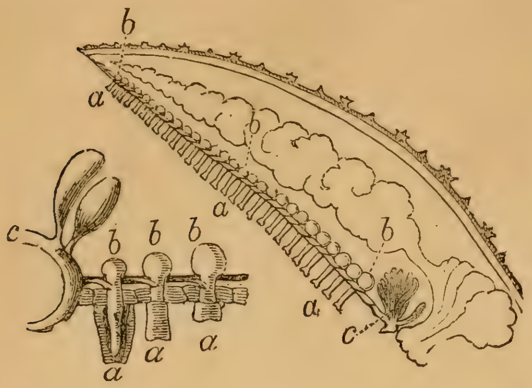


Fig. 67.—Ambulacra of Star-fish,

As seen in a longitudinal and vertical section of one of the rays; and three of them in a separate figure on a larger scale, in which they are shewn in different conditions: *a, a, a,* tubular feet; *b, b, b,* internal vesicles; *c,* the organ which supplies the fluid with which they are filled.

Articulata.

We come now to the great division of the animal kingdom called by Cuvier *Articulata* or Articulated Animals. The name refers not to the possession of articulated or jointed members, but to the articulated structure of the whole body. The Articulata are composed of segments jointed together in a line, each segment being formed of one or more rings, which in some appear externally as mere folds of a soft skin, as in worms, and in others are covered with a hard substance similar in composition to the bones of vertebrated animals, as in crabs, lobsters, &c. In some of the Articulata, the rings are almost equally developed, and the body is hardly otherwise divided into segments; in others, the rings differ

[1] From Latin *ambulare*, to walk.

very much in their development, and the segments are very distinct. A few only of the lowest Articulata, of which the earthworm may be taken as an example, have no distinct head, and no eyes nor other organs of special sense. Some of them have the mouth adapted merely for suction; but others have jaws or mandibles, and frequently several pairs of them, for seizing their food and tearing it in pieces. Their jaws do not open vertically, as in vertebrated animals, but laterally. There is no proper heart, but instead of it a *dorsal*[1] *vessel*, which runs along the central line of the body near the back or upper side. Respiration is effected by gills in those Articulata that live in water; but in those that live in air, by air-tubes, which ramify through the whole body, as in insects, or by mere air-sacs, as in the earthworm.

Annelidæ.—Many of the lowest Articulata have no limbs, but locomotion is accomplished by mere contraction and extension of the body. An earthworm, pushing its way forward, draws in the hinder part of its body as much as possible, the rings closing together, and then stretches out the fore-part as far as the integuments will permit. The earthworm belongs to a class called *Annelidæ* or *Annelids*, from Latin *annulus*, a ring. They have all very much the same form, and none of them have limbs, but many, higher in the scale of organisation than the earthworm, have eyes, and some have feelers or tentacles. Most of them live in water and respire by gills.

Leeches belong to an order of Annelids differing from all the rest in their mode of locomotion, which is by means of suckers, one at each end of the body. The sucker at the fore-end of the body is also the mouth; and that of many species is admirably adapted not only for killing and eating the minute aquatic animals which constitute their ordinary food, but for making little wounds in the higher animals, when opportunity occurs, through which their blood may be sucked.

Myriapoda.—Next to the Annelids may be ranked the class called *Myriapoda*,[2] in which the same elongated form generally prevails, and the body is, in like manner, composed of a large number of almost equal rings. All the Myriapoda, however, have a distinct head, most of them have eyes, and they have *antennæ* like those of insects. The mouth is furnished with a complete masticating apparatus. The body is protected by a hard covering, or external skeleton. None of the Myriapoda have wings. They do not undergo so great transformations as insects, but issue from the egg somewhat like what they are ultimately to become. The higher kinds of Myriapoda, as Centipedes, feed on animal substances, or prey on small animals; the lower, as Gallyworms, generally feed on decaying vegetable matter.

[1] From Latin *dorsum*, the back.

[2] From Greek *myrios*, ten thousand, and *pous, podos*, a foot.

The organs called *antennæ* are jointed filaments with which the head is furnished, one on each side, and are evidently very delicate organs of touch. The creatures which possess them seem to feel their way by them, and to them is ascribed the bee's power of working in the dark. Some suppose that they are also organs of hearing, and by means of them it would appear that some insects, as bees and ants, have the power of communicating with each other. They possess great flexibility, but differ much in the number of joints of which they are composed, and also in their form, some being threadlike, some club-shaped, some feathered, &c. in endless variety.

Crustacea.—The remaining classes of Articulata—namely, *Crustacea*, *Arachnida*, and *Insecta*—all have the body generally less elongated than the *Annelidæ* and *Myriapoda*, the division into segments quite distinct, and the circulating and nervous systems much concentrated in those segments with which the organs of special sense and of locomotion are connected. All of them have articulated limbs, and Insects are also very generally furnished with wings, which neither Crustaceans nor Arachnids possess. The *Crustacea* derive their name from their external skeleton, the hard armour which in most of them covers the whole body, and which, in those of highest organisation, is very complex in its structure. The body in Crustaceans, as in Arachnids and Insects, consists of three segments, the head, thorax, and abdomen. In Crustaceans and Arachnids, the head and thorax are very much combined into one piece, whilst in Insects they are perfectly distinct. All the organs of special sense are connected with the head, and the limbs with the thorax; but in many Crustaceans, as the lobster, prawn, and shrimp, the principal organ of locomotion is the abdomen, which terminates in fan-like appendages. By bending the abdomen suddenly down under the thorax, they dart backward in the water. The limbs of some are adapted for swimming; those of others are used for walking at the bottom of the water or on dry ground. The first pair of legs is not unfrequently transformed into powerful claws or pincers, as in crabs and lobsters. The limbs of the first thoracic rings are, in many Crustaceans, organs not of locomotion, but connected with the mouth, and employed for tearing food. The respiratory organs of all the Crustaceans are adapted to an aquatic life; even those which live on land being generally inhabitants of damp places and breathing by means of gills. Crustaceans are all oviparous; and they undergo remarkable metamorphoses after issuing from the egg, before they attain their adult form, after which, however, they still increase in size, *moulting* or casting the shell frequently.

The minute Crustaceans, which abound in lakes, ponds, and rivers, as well as in the sea, are of great use in the economy of nature, consuming

organic matter which would otherwise pollute the water by its decay, and affording food for fish.

Arachnida.—The *Arachnida* are commonly regarded as intermediate between Crustaceans and Insects. They have generally eight legs; although some, like insects, have only six. None of them have wings. The higher kinds—spiders and scorpions—breathe by means of pulmonary cavities; the lower—mites and ticks—by air-tubes. All of them have two or more eyes; many have eight. Some of the lowest Arachnida are parasitic upon insects, and a few live on decaying animal or vegetable substances, of which we have an example in the cheese-mite. In this and other mites and ticks, the mouth is a mere proboscis formed for suction; but spiders and scorpions have a mouth fitted for tearing and masticating their prey. Scorpions are remarkable for the sting at the tip of the tail, the tail itself being a prolongation of the abdomen. Spiders also subdue their prey by means of poison; but it is emitted through the mandibles. Both spiders and scorpions prey chiefly on insects; but there are very large spiders in the tropical parts of South America which occasionally prey on small birds. Many spiders catch their prey by stealthily approaching it, and suddenly springing upon it; but others employ *webs* for this purpose, the spider lurking in a corner of the web till the vibrations of its threads announce that an insect is entangled in its meshes. Spiders' webs are formed of a substance exuding from small protuberances called *spinnerets*, at the extremity of the abdomen. This substance is at first glutinous, but dries into thread as soon as it comes into contact with the air.

Insecta.—Insects,[1] so named from the extremely marked division of the three segments which form the body, are the most important and numerous class of Articulata. The segments are often so deeply divided that the slenderness to which the body is reduced between them cannot be contemplated without admiration, as in the neck of a wasp, or in the link which connects its abdomen with its thorax. The first segment is the *head*, which may be regarded as formed of several rings, modified and condensed together till their character as distinct rings is lost. The second segment is the *thorax*, which is always formed of three rings, closely combined, but easily distinguishable. The third segment is the *abdomen*, usually consisting of nine rings. All insects in their adult state have six legs; some are destitute of wings; others have two, and others four; but no insect, and indeed no animal, has any other number, and the only animals having four wings are insects. The external covering of the body of insects is of a horn-like substance, in most parts hard, but more or less flexible. It is the principal framework of the body, and to it the muscles are attached. Respiration is extremely

[1] Latin *insecta*, cut into, from *in*, into, and *seco*, to cut.

active in insects; and they display, in general, an extraordinary degree of activity and muscular energy. The flight of many kinds is far more rapid, in proportion to their size, than that of birds; others display a similar superiority in running, swimming, and digging or burrowing; whilst the leaping of many, as fleas and grasshoppers, and the springing of others, as cheese-hoppers, greatly exceed that of which any vertebrate animal is capable.

Insects feed on very different kinds of food. Some prey on other insects; some devour animal, and some vegetable substances; some suck the juices of animals, some the juices of plants or the honey of their flowers. The mouth of many is adapted for gnawing, cutting, or tearing; that of others, for sucking. An insect's mouth of the former kind is very complex in structure; and although the mouth adapted for sucking is apparently much more simple, it in reality consists of the same parts, but very much modified and united. The eyes of insects are of two kinds—*simple* and *compound*. Some have simple eyes only, others have only compound eyes; but the greater number have two large compound eyes on the sides of the head, and three small simple eyes between them. A compound eye is an organ of most remarkable structure. When examined through the microscope, its surface is seen to be divided into a great number of hexagonal facets, which are in fact *corneæ*. In the ant, there are only about fifty of these facets in each eye; but in the common house-fly, there are about four thousand, in butterflies, upwards of seventeen thousand, and in some beetles, more than twenty-five thousand. Each cornea may be regarded as belonging to a distinct eye, provided with a nervous apparatus, lens, iris, and pupil of its own. The eyes of insects cannot be turned to one side, like those of vertebrate animals, and for the want of this power, compensation is made by the number of eyes, each looking in its own particular direction.

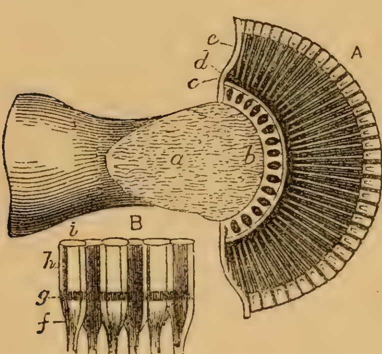


Fig. 68.—Section of the Eye of a Cockchafer (highly magnified):

A, section: *a*, optic ganglion, into which the optic nerve swells; *b*, nerves arising from its surface, and proceeding to the general retina; *c*, general retina; *d*, layer of pigment, in front of the general retina; *e*, optic nerves of the individual eyes which form the compound eye. B, a group of these, much magnified: *f*, bulb of optic nerve; *g*, layer of pigment; *h*, vitreous humour; *i*, cornea.

Insects, in general, take no care of their eggs after depositing them; but they are guided by wonderful instincts to select the proper situations for the deposition of them, so that the young, when hatched, may

find suitable food, although this food is often a kind quite different from that of the insect in its adult state. Some insects, however, as bees, wasps, ants, and earwigs, pay great attention to their young. The stage of development at which insects issue from the egg is very different in different tribes. In general, however, they undergo very remarkable metamorphoses. A worm, inhabiting a muddy pool, becomes a winged creature that sports in the air; a crawling caterpillar, that greedily devours some kind of herbage with its horny jaws, eating vastly more in proportion to its size than an ox, is converted into a splendid butterfly, flitting from flower to flower, and feeding only on nectareous juices. The first stage of insect-life, after the egg is hatched, is called the *larva* [1] stage, and in this the young insect generally increases much in size. Caterpillars are the larvæ of butterflies, moths, and hawk-moths; grubs are the larvæ of beetles; maggots are the larvæ of two-winged flies, such as the house-fly and blow-fly. The next stage into which insects pass is the *pupa* [2] stage, in which those that undergo *complete* metamorphoses are almost quite inactive, and take no food. The pupa of a butterfly, a moth, or a hawk-moth is called a *chrysalis* [3] or chrysalid, from the golden spots with which many such pupæ are adorned. Chrysalids are often enclosed in a horny membranous case. Many larvæ, when about to change into the pupa state, spin *cocoons* or silken envelopes in which they undergo their transformation, and which serve for the protection of the inactive and helpless pupæ. Silkworms are the larvæ of certain species of moth, which, on undergoing their transformation into pupæ, spin for themselves cocoons, the thread of which is *silk*. The cocoon of the common silkworm exhibits externally a loose gauze-like covering, within which is a compact and close oval ball; yet all this is one continuous thread, which may sometimes be unwound to the length of one thousand feet. The perfect insect is formed within the covering of the pupa, attaining there its full proportions, and ready to use its wings, its legs, and all its other organs within a few moments after it has emerged into the open air.

Fig. 69.—Purple Emperor Butterfly: The larva and pupa or chrysalis are shewn below—the larva to the right, and the chrysalis to the left.

[1] Latin *larva*, a mask. [2] Latin, 'a doll.' [3] From Greek *chrysos*, gold.

Insects are all animals of small size. The largest are tropical, amongst which are butterflies of almost a foot across the expanded wings. Insects abound far more in warm than in cold climates. The different species are very numerous, those of beetles alone exceeding in number all the kinds of vertebrated animals.

A few species of Insects are important for their usefulness to man ; but a far greater number are remarkable for the injuries they inflict by the destruction of herbage and crops or of articles of food or raiment. Of noxious insects, locusts may perhaps be regarded as the chief. Of insects useful to man, bees and silkworms deserve to be first named, and after them the cochineal insect and blistering-flies. There are a few others to which we are indebted for substances useful in medicine and the arts.

The instincts and habits of insects are very various and interesting. Many volumes have been written on those of bees and ants alone.

Of the orders into which the class of Insects is divided by systematic naturalists, we must be contented with very briefly noticing only the most important. Taking first the insects which undergo complete metamorphoses, and in their perfect state have the mouth fitted for gnawing, tearing, and masticating, we find the order *Coleoptera*,[1] distinguished by having the first pair of wings modified into hard sheaths —called *elytra*, or wing-cases—to cover the second pair when not in use, and to protect the upper side of the abdomen, the wings being folded crosswise under these wing-cases. Coleopterous insects are sometimes collectively called *beetles*, although many of them are familiarly known by other names, as chafers, weevils, lady-bugs, &c. The glowworm and fireflies belong to this order, as do also the valuable cantharides, or blistering-flies.—The order *Orthoptera*[2] differs from Coleoptera chiefly in having the wing-covers of a soft substance, somewhat resembling parchment, and the wings folded longitudinally in a fan-like manner. To this order belong locusts, grasshoppers, and crickets ; also those curious insects which, from their resemblance to leaves, twigs, and other objects, are known as leaf-insects or walking-leaves, walking-sticks, &c.— The order *Neuroptera*[3] consists of insects having mouths similar to those of the orders already noticed, and four nearly equal and membranous wings, all adapted for flight, not folded in any way when at rest, and divided by their nervures—ribs or veins—into a delicate network. To this order belong dragon-flies, may-flies, ant-lions, and termites or white ants. These last-named insects have social habits resembling those of the true ants. The great ant-hills of Africa and South America are constructed by them.—The order *Hymenoptera*[4] contains a vast number of

1 From Greek *coleos*, a sheath, and *pteron*, a wing.

2 From Greek *orthos*, straight, and *pteron*, a wing.

3 From Greek *neuros*, a nerve or string, and *pteron*, a wing.

4 From Greek *hymen*, a membrane, and *pteron*, a wing.

species, among which are ants and bees. They have the mouth furnished with mandibles for cutting and tearing, but other parts of it formed for suction. The wings are four in number, membranous, not folded when at rest, the first pair larger than the second, the wings of the same side united in flight by little hooks. Many species of this order have stings, and they are the only insects which have.

Among the orders of insects which undergo complete metamorphoses, but, in their perfect state, have the mouth formed only for suction, the first that demands notice is the order *Lepidoptera*,[1] to which butterflies, moths, and hawk-moths belong. The mouth has a long trunk, coiled up when not in use ; the wings are four in number, membranous, and covered with minute closely set scales, of very various forms. Great beauty appears in the whole order.—The order *Diptera*[2] contains all the two-winged insects commonly known as *flies*, also midges, gnats, &c. The number of species is immense. The mouth is formed for suction alone.

The insects which undergo no metamorphosis are comparatively few. They are all destitute of wings. Many of them are parasitical on other animals.

Mollusca.

Coming now to the primary division of the animal kingdom called *Mollusca*, we return to the consideration of animals far lower in organisation than those which have last been under notice, and ascend as by a new path to higher tribes ; for there is not in nature a regular unbroken gradation, as some have fancied, from the lowest to the highest forms of animal life. But in the highest Mollusca we have a nearer approach than in any of the other animal sub-kingdoms, to the highest of all, that of *Vertebrata*. Many of the lower Mollusca—those forming the order *Polyzoa*[3] —were until recently ranked among Zoophytes, and they have a strong general resemblance to the polypes already noticed as belonging to the great group of *Cœlenterata*. They are, like them, of minute size, and many have a similar coralline fabric. They also resemble them in multiplying by gemmation and forming compound animals. In the lowest groups of Mollusca, we find only one principal nervous ganglion. In the higher groups, there are several ganglia lying somewhat irregularly in different parts of the body, and communicating by nervous threads with a larger mass. It is only in the highest Mollusca that a distinct head is found, bearing organs of special sense. The lowest groups have no distinct heart, but all the higher possess it. The bilateral symmetry of form, almost universal in articulated and in vertebrate animals, is comparatively

[1] From Greek *lepis*, a scale, and *pteron*, a wing.
[2] From Greek *dis*, twice, and *pteron*, a wing.
[3] From Greek *polys*, many, and *zōon*, an animal.

rare in the Mollusca. The shell with which many species are protected, has not in the least degree the nature of an external skeleton, no muscles being attached to it but those which are necessary for the opening and shutting of its own valves. It is a mere calcareous exudation from the *mantle*, a thick, soft, flexible skin, with which, in all the Mollusca, the whole body is invested. Many Mollusca have no shell; many have the shell in a single piece, which is often a spiral tube closed at one end, and gradually widening to its open extremity. Such shells are called *univalves*.[1] Snails, whelks, and periwinkles afford familiar examples of the most common form of univalve shells. Somewhat different forms may be seen in limpets, cowries, &c. The shells of many molluscs are composed of two valves, as those of oysters, mussels, &c., which the animal is able to open and shut at pleasure. Such shells are called *bivalve*.[2] In a small number of molluscs, the shell is composed of a greater number of pieces, and such shells are said to be *multivalve*,[3] but the multivalve molluscs differ little from univalves in their general organisation.

All molluscs have the power of locomotion, at least in the earliest stage of their existence; although many of the lower tribes soon lose it, and become permanently fixed in one spot. The modes of locomotion are various. Many molluscs move by means of a muscular structure in some particular part of the mantle, termed the *foot*, which in some, as in the cockle, is an organ for springing, in others for burrowing, in many for crawling, and in some for swimming. In the highest of all orders of molluscs, the *Cephalopoda*[4]—of which the cuttle-fish and squid are examples—the head is furnished with tentacles armed with suckers, and by means of these the animal drags itself along, whilst the body is also often provided with fin-like expansions, which serve for swimming. The respiration of Mollusca generally takes place by gills; but slugs and snails, which do not inhabit water, have a pulmonary sac or cavity lined with a vascular network.

Vertebrata.

The highest primary division of the animal kingdom is that of *Vertebrata*, comprising the five classes of Fishes, Amphibians, Reptiles, Birds, and Mammals, the first-named being the lowest, and the last the highest of all. All the classes of Vertebrata agree in what may be called a general type of structure, exhibited in its highest perfection in man, and of which some account has already been given under

[1] From Latin *unus*, one, and *valva*, a valve.
[2] From Latin *bis*, twice, and *valva*, a valve.
[3] From Latin *multus*, many, and *valva*, a valve.
[4] From Greek *cephalē*, the head, and *pous*, *podos*, a foot.

PHYSIOLOGY. One of the most marked characteristics of the vertebrate animals is that indicated by their common name; they have an internal bony skeleton, to which the muscles are affixed, and of which the principal part is the backbone, terminated at the anterior extremity by the skull. They have in general four limbs, corresponding to the arms and legs of man, but very variously modified as organs of mere locomotion, and as organs also of prehension; and assuming not only the characters of arms and legs, terminated by hands or feet, but also of fins, wings, &c. Some vertebrate animals have only one pair of limbs instead of two, a few have no limbs at all. No vertebrate animal has any other number of limbs than two or four. The limbs are always formed of bones jointed to the backbone and one to another, surrounded with muscles, and covered with skin. All vertebrate animals have a distinct head, a skull containing the brain, and a spinal cord extending through the centre of the backbone. They have a system of circulation dependent on the action of a muscular heart with two or more cavities. Those which live in water breathe by gills, those on dry land by lungs. The digestive system, although exhibiting a variety of modifications as great as the external form, presents always the same general characters. The mouth, for example, is always situated in the front of the head, and has two bony jaws articulated to the other bones of the head. A tongue is also always present in the mouth, an organ to which nothing truly corresponding is to be found in any invertebrate tribe.

Fishes.—The class of Fishes consists of animals that all live in water, and at all stages of their existence breathe by gills. In number—both of individuals and of different kinds—fishes are supposed to exceed all other vertebrate animals together. Not only the sea, but lakes and rivers abound in them, even the waters of hot springs and the pools of caverns have their peculiar species. Their form is adapted to easy progression through water. The four limbs which belong to the vertebrate type are generally all present, assuming the form of fins—the first pair, situated on the *breast*, being the *pectoral*[1] fins (*p*, fig. 70), and the second the *ventral*[2] (*v*, fig. 70), their normal position being on the *belly*. The latter are liable to great changes of position, and are often found close under the pectoral fins, and sometimes before them, quite on the *throat* of the fish, in which position they are called *jugular*[3] fins. Fishes, however, have also other fins, not so closely connected with the proper skeleton, and placed singly on the middle line, both above and below. One of these, the *caudal*[4] or tail fin (*c*, fig. 70), is the principal organ of locomotion, the whole muscular power of great part of the

[1] From Latin *pectus*, the breast.
[2] From Latin *venter*, the belly.
[3] From Latin *jugulum*, the throat.
[4] From Latin *cauda*, a tail.

body being brought to bear in its stroke. The fins on the *back* are called *dorsal* fins (fig. 70, d^1, first dorsal; d^2, second dorsal), and that behind the anus, the *anal* fin (*a*, fig. 70). Fishes differ from all other vertebrate animals in having sets of bones not connected with the backbone or the internal skeleton. These bones support the vertical fins, and are thickest at the skin, from which they penetrate towards the vertebræ. Fishes consume little air in respiration, and are *cold-blooded* animals, having in general a temperature little above that of the water in which they live.

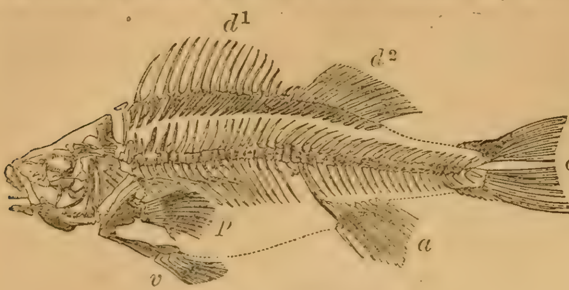


Fig. 70.—Skeleton of a Fish.

The mouth of fishes is their only organ of prehension. In some it is extremely small, in others extremely large; in some destitute of teeth, in others furnished with a multitude of very minute teeth, in others, again, with a great number of large and strong teeth. In some, as lampreys, it forms a sucker, by which the fish can both affix itself and suck up the blood of the animal on which it preys. The teeth of fishes are more various in number, form, and position than those of any other animals. Some fishes feed on vegetable food, such as the leaves of water-plants; but most of them feed on animal food, of which there is no kind that does not seem to be particularly agreeable to some of them.—Fishes are generally oviparous, and the multitude of their eggs is prodigious, as may be seen in the roe of a herring or a cod; a few kinds are *ovoviviparous*,[1] the eggs being hatched within the body of the parent, and the young produced in a living state.—Fishes are generally covered with scales, which are variously formed and arranged. Some kinds have large bony plates instead of scales.—Of the uses of fishes to man, by far the most important is that of supplying him with food. It is impossible here to enumerate the fishes highly valuable in this respect. Some of them are to be found inhabiting both salt and fresh waters, in all parts of the world. The herring, cod, and salmon are, however, the three species of highest economical importance.

Fishes are divided into two great sections or sub-classes—OSSEOUS[2] FISHES, which have hard bones, and CARTILAGINOUS FISHES, of which the bones are cartilaginous, and destitute of true bony fibres. The Osseous Fishes are far more numerous than the Cartilaginous; the

[1] From Latin *ovum*, an egg, and *viviparus*, bringing forth its young alive.
[2] *Bony*, from Latin *os*, a bone.

most important of the latter section being the tribes of Sharks, Rays (Skates, &c.), Sturgeons, and Lampreys.

Amphibians.—The class *Amphibians*[1] receives its name from the fact that many of the species belonging to it are capable of living either on dry land or in water. Many naturalists regard it merely as an order of the class of Reptiles, to which the name of *Batrachian*[2] *Reptiles* is given, the *frog* being taken as the type of the whole. The most essential differences between Amphibians and Reptiles are, that young Amphibians undergo metamorphoses, and that Amphibians breathe by gills alone in the earlier part of their life, whilst in their adult state most of them breathe by lungs alone, although some have both lungs and gills. Most of the Amphibians, in an adult state, have four limbs, although in some these are altogether wanting, and others have only one pair; but in the early stages of their life none of them have limbs at all, and their form is fish-like, of which we have a familiar example in the tadpole, the young of the frog.

Fig. 71.—Successive stages of the Frog:
In the order of the numbers—from the egg almost to the perfect form.

Frogs, toads, newts, and salamanders are the best known Amphibians; but some of those of other countries greatly exceed those of Britain in size.

Reptiles.—*Reptiles*[3] agree with Amphibians and Fishes in being cold-blooded. They differ from Amphibians in breathing by lungs throughout the whole period of their existence. Three orders of reptiles are generally

[1] From Greek *amphibios*, having a double life.
[2] From Greek *batrachos*, a frog.
[3] From Latin *repo*, to creep.

recognised by naturalists: *Ophidians*[1] or Serpents; *Saurians*,[2] including lizards, crocodiles, and all species of lizard-like form; and *Chelonians*,[3] containing tortoises, turtles, &c.

SERPENTS have no limbs, and in general the body is very much elongated. The body and tail are covered with scales, the head very often with plates. The vertebræ and ribs are extremely numerous, some serpents having more than three hundred pair of ribs. A serpent moves by means of its ribs and the scales of the abdomen, which are joined to the ribs by slender cartilages, and take hold of the surface over which the animal passes. Many serpents not only glide over the ground with great rapidity, but climb trees with comparative ease. The vertebræ are so formed and jointed together as to give great pliancy to the body. Serpents abound chiefly in the warm parts of the world, to which also the largest species belong, and those of which the venom is most deadly. Venomous serpents depend on their poison-fangs for the capture of their prey. The fangs are a pair of tubes firmly fixed into a movable bone in the front of the upper jaw. When not in use, they are laid back on the roof of the mouth; but when the animal is irritated, and about to assail its enemy or its prey, they stand out like two lancets. Above them, towards the back of the head, is a large gland for the production of the poison, which passes down the fangs into the wounds which they make. Many serpents, however, are not venomous, but depend on other means for catching their prey, some feeding chiefly on insects or very small animals; and some, the largest and most powerful of all—as the *Boa-constrictor* and the *Pythons* of the East Indies—killing even large quadrupeds by mere muscular effort when they have laid hold of and coiled themselves around them.

LIZARDS may be regarded as exhibiting the perfection of the Saurian type. In them, and in chameleons, iguanas, &c., the body is covered with scales; but in crocodiles and alligators it is covered with bony plates, and these animals have therefore been separated from Saurians by some naturalists, and constituted a distinct order under the name of *Loricata*.[4] They are all large reptiles, much larger than any of the scale-covered Saurians, and formidable from their strength and voracity. They inhabit the lakes and rivers of warm countries. The scale-covered or true Saurians are also chiefly inhabitants of warm countries, and most of them love dry situations and sunshine. Some climb trees, and generally live in them, pursuing there their insect prey. A few of them, as the *Iguana* or *Guana* of the West Indies, feed on leaves and fruits. The

1 From Greek *ophis*, a serpent.

2 From Greek *sauros*, a lizard.

3 From Greek *chelonē*, a tortoise.

4 That is, *mailed*, from Latin *lorica*, a coat of mail.

Iguana, although of repulsive appearance, is highly esteemed as an article of food, and is the only Saurian reptile which is so used, except by savage tribes.

Very different from all other reptiles in structure and general appearance is the last order, that of CHELONIANS, all of which are popularly known by the names of tortoise and turtle—the tortoises being those which live on land, and have their feet adapted chiefly for walking; the turtles, those which live in water, and whose limbs are mere paddles for swimming. The Chelonians are all inhabitants of warm countries. Their numbers in some places are astonishingly great. The species both of tortoises and turtles are very numerous, and some of them are highly esteemed for food. The useful substance called tortoise-shell is the hard covering of animals of this order. This covering is really bony, and therefore differs from the outer covering of all other vertebrate animals, being formed from the ribs, the vertebræ, and the breast-bone expanded into plates, and firmly jointed into each other, so as to acquire great solidity, particularly in tortoises, and give most perfect protection to creatures which have no other means of defence. Tortoises feed exclusively on vegetable food, but some of the aquatic Chelonians pursue and prey upon other aquatic animals. The jaws of Chelonians are not furnished with teeth, but are hard, sharp, and horny; they act in a manner somewhat resembling the mandibles of birds. All the Chelonians are oviparous. They lay a great number of eggs, which are covered with a calcareous shell like those of birds, whereas those of other reptiles have only a parchment-like covering. The eggs of turtles are a favourite luxury in the countries in which they can be obtained.

Birds.—Birds are the highest class of oviparous animals, and the only class having warm blood. They exhibit a great similarity in their general structure, and differ very widely in appearance and characters from every other class of animals. To this class belong all the vertebrate animals which are capable of true flight, except bats. The fore pair of limbs in birds serve them only as wings, never in any degree as arms or legs; those few birds in which they are too small to raise the body in the air, generally employ them to aid their swift running upon land, as the ostrich, or for swimming *under* water, as penguins, which in this manner pursue fish. The body of birds is covered with feathers, and this is one character in which all birds agree, and in which they differ from all other animals. The jaws of birds are much elongated, so as to form the bill, the organ chiefly used in seizing food. The bones of the wing are essentially the same with those of the arms of man, but very much modified to accommodate them to their different use. The bones which represent the fingers are much condensed and partially obliterated. The surface

necessary for striking the air is provided by feathers different from those of other parts of the body, called *wing-feathers* or *quills.* In many birds, similar feathers appear in the tail, which is used for governing flight. The mechanical adjustments by which the wings are fitted for use as organs of flight, are very beautiful. Birds do not rise or sustain themselves in the air because of any special lightness of their bodies, which are in fact much heavier than the air, but by the action of their wings upon it, and its resistance to them. The legs of birds consist of parts corresponding to those of the legs of man, but the thigh is short, and concealed within the body, the apparent thigh corresponding to the human leg, and the *shank,* which serves the bird as a leg, to a part of the foot.—Some birds are very useful to man, as affording, in their flesh and their eggs, valuable articles of food; but the number really of importance in this respect is very small in comparison with the multitude of species, and the useful kinds belong mostly to two orders, *Rasores* and *Natatores,* to be presently noticed.

We can only indicate in a few sentences the orders of birds. The order *Accipitres,*[1] *Rapaces,*[2] or *Raptores,*[3] contains birds of prey, the food of which is the flesh of animals, chiefly other birds and quadrupeds. They are characterised by great strength of claws and bill. The upper mandible of the bill is hooked and sharp. The claws also are generally hooked and sharp, and the feet formed for seizing prey. The wing is generally large and pointed. This order is divided into two groups, *Diurnal* and *Nocturnal,* the first containing eagles, falcons, hawks, vultures, &c.; and the latter consisting entirely of owls. —The order *Insessores*[4] is a very large one, consisting of birds which have weak, slender feet, not adapted for seizing prey, but generally for perching on trees. Like the Birds of Prey, and most of the birds of other orders, they have four toes, three directed forward, and one backward. The bill is weak and little curved. The wings are of moderate size, and generally rounded. Some of the Insessores feed chiefly on insects, some on seeds or fruits, some indifferently both on animal and vegetable food. To this order belong crows, thrushes, linnets, larks, sparrows, humming-birds, birds of paradise, &c.—The order *Scansores*[5] consists of birds very similar to Insessores, but having two toes behind and two before, so that their feet are peculiarly adapted for grasping and climbing. Parrots afford perhaps the best example of this order. Woodpeckers also belong to it. —The *Rasores,*[6] or Gallinaceous Birds,[7] have a bill of moderate size, short wings, a heavy body, weak toes, and short, stout claws. In general,

1 Latin, plural of *accipiter*, a hawk.

2 Latin *rapax*, rapacious.

3 Latin, plural of *raptor*, a seizer or plunderer.

4 Latin, 'sitters,' from *sedeo*, *sessum*, to sit.

5 Latin, 'climbers,' from *scando*, *scansum*, to climb.

6 Latin, 'scrapers,' from *rado*, *rasum*, to scrape.

7 From Latin *gallus*, a cock.

they have little power of flight, and seek their food on the ground. Many do not even perch on trees. They derive their name Rasores from their habit of *scraping* the ground in search of worms and insects, a habit which is scarcely found in any other birds. To this order belong the common fowl, the turkey, pheasant, quail, partridge, grouse, &c. Pigeons are also generally ranked in it.—The order *Cursores*[1] is a very peculiar one, distinguished by the shortness of the wings, which are not adapted for flight, and by long and strong legs, suited for rapid *running* on the ground. The species of this order are few; but all are birds of large size. The ostrich, cassowary, and emu belong to it.—The *Grallæ* or *Grallatores*,[2] are birds with long shanks and long toes, adapted for wading or for walking on sand or mud. The whole figure is generally slender; the neck often long. Many birds of this order have also long bills. Some of them feed on vegetables; others on insects, molluscs, small fish, &c. Most of them inhabit marshy places or the banks of rivers and the sea-shore. Some seek their food by inserting their long bills into mud. Herons, cranes, storks, bitterns, snipes, and woodcocks are examples of this order.—The order *Natatores*[3] is characterised by webbed feet, that is, by having the toes connected by a membrane, so as to be especially adapted for *swimming*. The bill varies very much in form, according to the habits and food of different kinds. Some, as penguins, have very short wings; others are long-winged birds of very powerful flight, as albatrosses, petrels, and other oceanic birds. Swans, geese, and ducks belong to this order; also gulls, terns, and sea-fowl in general.

Mammalia.—*Mammalia* or *Mammals*[4] are the highest class of animals. In them the brain assumes its most perfect form, and the highest degrees of intelligence are displayed, although in these respects there is much diversity in the different groups, the greatest perfection being reached in man, who, considered with regard to his mere animal nature, must be ranked in this class. The name refers to a characteristic of the class altogether peculiar to it, that the females *suckle* their young. All the Mammalia are viviparous, although the young are produced in very different stages of development. The skin of the greater number of mammals is covered with hair, a kind of covering peculiar to this class of animals. The limbs of some species are adapted merely for locomotion and for the support of the body; those of others are also organs of prehension. Marine species have them modified into paddles; and in the *Cetacea* (whales, &c.) the fore-limbs are represented by fins, whilst the hinder limbs are altogether wanting.

The class Mammalia is divided into three principal sections, according

1 Latin, 'runners,' from *curro*, *cursum*, to run.

2 Latin, 'stilt-walkers,' from *grallæ*, stilts.

3 Latin, 'swimmers,' from *nato*, *natatum*, to swim.

4 From Latin *mamma*, a teat.

to the character of the limbs and of their extremities—*Unguiculata*,[1] mammals having nails or claws; *Ungulata*,[2] mammals having hoofs; and *Mutilata*,[3] mammals having no hind-limbs, and the fore-limbs modified into fins. To the first of these sections, Unguiculata, man is referred; and for the single species so high in intelligence and endowments, so different from all other animals, the order *Bimana*[4] has been constituted, the name expressing the peculiar character of the adaptation of the extremities of the fore-limbs to the purposes of grasping, &c., as hands; whilst those of the hind limbs are merely feet, serving for the support of the body; this very difference between the fore and hinder extremities shewing that man is intended for an upright posture. In this respect, he is altogether peculiar, as all the lower mammals inhabiting the dry land ordinarily go upon all-fours, although this is somewhat disguised in monkeys by their climbing powers. Monkeys belong to an order called *Quadrumana*,[5] the extremities of all the four limbs being fitted for use as hands, by having thumbs opposed in action to the fingers, and the hind-limbs having often the greatest grasping power.—Cuvier's order, *Carnaria*,[6] so designated because consisting of species which chiefly subsist by preying upon other animals, is divided into three sub-orders—*Cheiroptera*, *Insectivora*, and *Carnivora*. (1) *Cheiroptera*,[7] or Bats, are the only winged mammals. The wings of bats are very different in structure from those of birds, and consist chiefly of the bones of the fore-limbs, and particularly the finger-bones, prodigiously lengthened and united by membrane. Most of the bats feed chiefly on insects, although some large tropical species eat fruits.—(2) The *Insectivora*,[8] as moles, shrews, and hedgehogs, are mostly small timid creatures. They do not all prey exclusively on insects, although all have their molar teeth beset with small tubercles for breaking up the hard coverings of insect prey.—(3) The sub-order *Carnivora*[9] includes the quadrupeds which chiefly prey upon other vertebrate animals. Their muscular energy is very great, their respiration and circulation very active. Their use in the scheme of nature seems to be to prevent the undue multiplication of herbivorous animals, which, unless thus checked, would soon destroy the vegetation of the earth, and unfit it for their own abode. Cuvier divided the Carnivora into three sections. The first section, named *Plantigrade*,[10] contains those which place the whole sole of the foot on the ground in walking, of which the families of Bears and Badgers are the most notable. The second section, *Digitigrade*,[11] contains those which walk on the tips of the toes only, of

1 From Latin *unguis*, a nail.
2 From Latin *unguis*, a hoof.
3 Latin, 'mutilated.'
4 Latin, 'two-handed.'
5 Latin, 'four-handed.'
6 From Latin *caro, carnis*, flesh.
7 From Greek *cheir*, a hand, and *pteron*, a wing.
8 Latin, 'insect-eating.'
9 Latin, 'flesh-devouring.'
10 From Latin *planta*, the sole of the foot, and *gradior*, to walk.
11 From Latin *digitus*, a finger, and *gradior*, to walk.

which the chief families are the *Felidæ*,[1] including all the cat kind, the lion, tiger, leopard, lynx, &c.; the *Canidæ*,[2] of which dogs, foxes, and jackals are examples; *Hyænidæ*, to which the hyæna belongs; *Viverridæ*,[3] of which the civet is the best known example; and *Mustelidæ*,[4] the weasel tribe, including the ermine, marten, ferret, polecat, otter, &c. The most fierce and exclusively carnivorous quadrupeds belong to the orders Felidæ, Viverridæ, and Mustelidæ. The third section of the Carnivora in Cuvier's system is called *Amphibia*, and consists of seals, sea-elephants, the walrus, and similar animals, all marine, and having their feet adapted mainly for swimming, their teeth and digestive system for preying upon fish. The sea-elephant is more than twice the size of the largest African or Indian elephant.—The order *Marsupialia*[5] is distinguished by the *pouch* in which the females carry their young, the young being produced at an earlier stage than in other mammals. It is a curious fact that almost all the quadrupeds of Australia belong to this order, whereas elsewhere almost the only marsupial animals in the world are the opossums of America. Opossums and kangaroos are the kinds of which the names are most familiar to us, but there are many others, some of which are herbivorous and some carnivorous. The Marsupialia seem to be generally inferior to other mammals in intelligence.—The order *Rodentia*[6] consists of quadrupeds which have the front teeth—two in each jaw—large and of a peculiar structure, chisel-like, so as specially to adapt them for *gnawing*. Hares, rabbits, rats, mice, squirrels, and beavers are familiar examples of this order, the species of which are very numerous, and all of them small animals.—The order *Edentata*[7] is composed of animals, some of which are absolutely *destitute of teeth*, whilst others have small teeth only in the back part of their jaws. To this order belong sloths, armadillos, and ant-eaters, animals of very various habits, and differing in the nature of their food, yet exhibiting a general similarity of structure.

The *Ungulata* or hoofed quadrupeds are divided into two orders, *Pachydermata*[8] and *Ruminantia*.[9] The first of these orders contains elephants, tapirs, rhinoceroses, the hippopotamus, hogs, &c., all characterised by remarkable *thickness of skin*, and all feeding on vegetable food, although in other characters there is great diversity. To this order belong the largest of land animals. A section of the order very distinct from the rest, characterised by undivided hoofs, contains the horse tribe, the horse, ass, zebra, &c. The Ruminantia are the only animals in which the habit of *chewing the cud* is found. All of them are

1 From Latin *felis*, a cat.
2 From Latin *canis*, a dog.
3 From Latin *viverra*, a ferret.
4 From Latin *mustela*, a polecat.
5 From Latin *marsupium*, a pouch.
6 Latin, 'gnawers,' from *rodo*, to gnaw.
7 Latin, 'toothless,' from *e*, without, and *dens*, *dentis*, a tooth.
8 From Greek *pachys*, thick, and *derma*, skin.
9 Latin, 'chewing the cud,' from *rumino*, to chew again.

strictly herbivorous. To this order belong the families *Camelidæ*, containing the camel and dromedary of the old world, and the lama, alpaca, &c., of the new; *Camelopardidæ*, containing the camelopard or giraffe alone; *Cervidæ*,[1] containing the numerous species of deer; *Antilopidæ*, containing the numerous species of antelope; *Bovidæ*,[2] containing oxen, buffaloes, bisons, &c.; and *Capridæ*,[3] containing sheep and goats. It will be seen that many of the animals most useful to man belong to this important order.

The *Cetacea*[4] all inhabit the ocean, and have a fishlike form, but, unlike fishes, the tail is placed horizontally, so that they have great facility in diving and in ascending to the surface of the water, which they are under the necessity of doing very often, in order to breathe. They are as careful of their young as any land mammals. The largest whales sometimes attain a length of seventy or eighty feet, yet the food of these great animals consists entirely of molluscs and other small marine creatures, taken into the mouth along with floods of water, which soon afterwards escapes, the food having been sifted from it by the plates and fibres of *whalebone*, with which the great cavity of the mouth is filled. Other Cetacea, however, have no whalebone, but are furnished with teeth, and prey on fishes, of which we have an example in the porpoise of the British coasts. Two or three species of Cetacea differ entirely from the rest, in being herbivorous and having teeth like those of ordinary herbivorous quadrupeds. Such are the Dugong[5] of the Eastern Archipelago, and the Manatee or Lamantine of the West Indies. Their food consists partly of sea-weeds and partly of the luxuriant herbage on the banks of tropical estuaries, on which they browse when the tide enables them to reach it.

We have not attempted to point out the many and various uses of the Mammalia; nor have we been able, in almost a single instance, to allude to the beauty or peculiarity of their forms, to their habits, their intelligence, their affections, their capacity for domestication, and the like. It is a wide field which opens out before the student, who will everywhere see more and more to call forth his admiration of the Creator's wisdom and goodness.

1 Latin *cervus*, a deer.
2 From Latin *bos*, *bovis*, an ox.
3 From Latin *capra*, a goat.
4 From Latin *cete*, a whale.
5 See bottom of page 106.

TABLE OF THE CLASSIFICATION OF ANIMALS.

*** *This table does not contain a complete classification of animals, but only the great Divisions and the principal Classes and Orders, as given in the preceding pages.*

DIVISION I.—PROTOZOA.

Animals of the most simple organisation, having no nervous system, and, with the exception of one group, no mouth or intestinal canal.

CLASSES.—**Rhizopoda—Sponges—Infusoria.**

DIVISION II.—CŒLENTERATA.

Animals with soft bodies composed of two layers, the digestive cavity being surrounded by tentacles.

DIVISION III.—RADIATA.

Radiated or Rayed animals, as star-fishes.

CLASS.—**Echinodermata**, as star-fishes, sea-urchins.

DIVISION IV.—ARTICULATA.

Articulated or Jointed animals.

CLASS I.—**Annelidæ**, as earthworms, leeches.
" II.—**Myriopoda**, as centipedes, gallyworms.
" III.—**Crustacea**, as the crab, lobster, shrimp.
" IV.—**Arachnida**, as the spider, scorpion, mite.
" V.—**Insecta**, insects.
ORDER 1. **Coleoptera**, insects having wing-cases, as the beetle, glow-worm, firefly.
" 2. **Orthoptera**, insects having soft wing-covers folded like a fan, as the locust, grasshopper, cricket.
" 3. **Neuroptera**, insects having four wings divided into a net-work, as the dragon-fly, may-fly, white ant.
" 4. **Hymenoptera**, insects having membranous wings, and many of them stings, as the ant, bee.
" 5. **Lepidoptera**, insects which have the wings covered with scales, and undergo a complete metamorphosis, as butterflies, moths.
" 6. **Diptera**, two-winged insects, as flies, midges, gnats.

DIVISION V.—MOLLUSCA.

Soft-bodied animals, as snails, whelks, limpets, oysters, mussels, cuttle-fish, squids.

DIVISION VI.—VERTEBRATA.

Animals having an internal skeleton with backbone and skull.

CLASS I.—**Fishes**, cold-blooded animals, as the herring, cod, salmon, shark.
SUB-CLASS 1. **Osseous Fishes**, as the cod, salmon, herring.
" 2. **Cartilaginous Fishes**, as the shark, skate, sturgeon.
" II.—**Amphibians**, cold-blooded animals, living either on land or in water, as the frog, toad, newt; and breathing by gills when young, and by lungs when mature.
" III.—**Reptiles**, cold-blooded animals, breathing by lungs at all periods of life.
ORDER 1. **Ophidians** or Serpents.
" 2. **Saurians**, as lizards, crocodiles.
" 3. **Chelonians**, as tortoises, turtles.
" IV.—**Birds**, warm-blooded animals, oviparous, and covered with feathers, the fore-limbs being modified into wings.
ORDER 1. **Accipitres, Rapaces, or Raptores**, birds of prey.
GROUP 1. **Diurnal**, as eagles, falcons, hawks, vultures.
" 2. **Nocturnal**, as owls.

CLASS IV.—*continued.*

ORDER 2. **Insessores**, with feet adapted only for perching, as crows, thrushes, linnets, larks, and sparrows.

" 3. **Scansores**, having feet specially adapted for climbing, as parrots, cuckoos, and woodpeckers.

" 4. **Rasores** or **Gallinaceous Birds**, having short stout claws, adapted for scraping the earth in quest of food, as the common fowl, turkey, peacock, pheasant, partridge, &c.

" 5. **Cursores**, large birds with long legs and very short wings, incapable of flight, as the ostrich, cassowary, and emu.

" 6. **Grallæ** or **Grallatores**, long-legged birds, with feet adapted for wading, or for walking on sand or mud, as herons, cranes, storks, snipes, and woodcocks.

" 7. **Natatores**, aquatic birds with webbed feet, as swans, geese, ducks, gulls, and penguins.

" V.—**Mammalia** or **Mammals**, warm-blooded animals, viviparous, and suckling their young.

SECT. 1. **UNGUICULATA**, having nails or claws.

ORDER 1. **Bimana**, having the fore-limbs terminated by hands, the hinder limbs by feet. Man is the only species.

" 2. **Quadrumana**, having all the four limbs terminated by hands, and capable of grasping, as monkeys.

" 3. **Carnaria**, mammals which subsist chiefly by preying on other animals.

SUB-ORDER 1. **Cheiroptera**, winged mammals, all generally known by the name of bats.

" 2. **Insectivora**, small quadrupeds having teeth adapted specially for insect prey, as shrews, moles, and hedgehogs.

" 3. **Carnivora**, quadrupeds chiefly preying on other vertebrate animals.

SECT. 1. **Plantigrade**, walking on the whole sole of the foot, as bears.

" 2. **Digitigrade**, walking on the toes only, as the cat, lion, tiger, &c.—dog, fox, civet, weasel.

" 3. **Amphibia**, marine animals, having feet adapted mainly for swimming, as seals, the walrus, and the sea-elephant.

" 4. **Marsupialia**, distinguished by the pouch in which the females carry their young, as kangaroos and opossums.

" 5. **Rodentia**, having the front teeth specially adapted for gnawing, as hares, rabbits, rats, mice, squirrels, and the beaver.

" 6. **Edentata**, having no teeth, or only small teeth in the back part of the jaws, as sloths, ant-eaters.

SECT. 2. **UNGULATA**, having hoofs.

ORDER 1. **Pachydermata**, having a thick skin, and feeding on vegetable food, as elephants, rhinoceroses, the hippopotamus, hogs, the horse, ass, and zebra.

" 2. **Ruminantia**, herbivorous animals, chewing the cud, as the camel, giraffe, deer, ox, buffalo, &c.—sheep, goat.

SECT. 3. **MUTILATA**, having no hind-limbs, and the fore-limbs modified into fins.

ORDER, **Cetacea**, as whales and porpoises.

CLASSIFICATION OF ANIMALS.

The student ought to make himself thoroughly familiar with the primary DIVISIONS of the animal kingdom and their distinctive characters. They are sometimes called SUB-KINGDOMS, and some of them are divided into *sections*, as Fishes into *Osseous* and *Cartilaginous*. They are all divided into *classes*, and these again into *orders;* which are further divided into *families*, and these into *genera*. A genus sometimes contains only one species, when it differs so much from all others as to require such a separate place ; but some genera contain a great number of species, nearly resembling each other. A *species* consists of those individuals which are derived, or may be supposed to be derived, from a common parentage. A species is designated by the name of its genus with another word added—sometimes a name derived from the country which it inhabits, or from the name of its discoverer, often a Latin adjective, and sometimes indicative of some of its most marked characters. Thus the robin redbreast is *Sylvia rubecola; Sylvia* being a genus that includes many similar birds, and belonging to a family called *Sylviadæ*, which contains many genera, all of small birds, such as those known by the name of warblers, and amongst which are our finest song-birds. The relations of the terms *Division, Class, Order, Family, Genus,* and *Species* ought to be carefully observed and remembered.

We give the following as specimens of the classification of animals, selecting well-known species :

THE OX.

Species	*Bos taurus.*
Genus	*Bos.*
Family	*Bovidæ.*
Order	*Ruminantia.*
Class	*Mammalia.*
Division	*Vertebrata.*

THE ROBIN REDBREAST.

Species	*Sylvia rubecola.*
Genus	*Sylvia.*
Family	*Sylviadæ.*
Order	*Insessores.*
Class	*Aves* (Birds).
Division	*Vertebrata.*

THE COMMON LAND-TORTOISE.

Species	*Testudo Græca.*
Genus	*Testudo.*
Family	*Testudinidæ.*
Order	*Chelonia.*
Class	*Reptilia* (Reptiles).
Division	*Vertebrata.*

THE COMMON FROG.

Species	*Rana temporaria.*
Genus	*Rana.*
Family	*Ranidæ.*
Order	*Batrachia.*
Class	*Amphibia.*
Division	*Vertebrata.*

THE COMMON TROUT.

Species............*Salmo fario.*
Genus...............*Salmo.*
Family............*Salmonidæ.*
Order...............*Malacopterygii.*
Class................*Pisces* (Fishes).
Division...........*Vertebrata.*

THE GARDEN SNAIL.

Species............*Helix nemoralis.*
Genus...............*Helix.*
Family............*Helicidæ.*
Order...............*Pulmonata.*
Class................*Acephala.*
Division...........*Mollusca.*

THE LOBSTER.

Species............*Homarus vulgaris.*
Genus...............*Homarus.*
Family............*Astacidæ.*
Order...............*Decapoda.*
Class................*Crustacea.*
Division...........*Articulata.*

THE COMMON STAR-FISH, CROSS-FISH, OR FIVE FINGERS.

Species............*Uraster rubens.*
Genus...............*Uraster.*
Family............*Asteriadæ.*
Order...............*Asteroidea.*
Class................*Echinodermata.*
Division...........*Radiata.*

Dugong.

BOTANY.

Botany, from the Greek *botanē*, an herb, is the science which treats of *plants* or the Vegetable Kingdom. That part of the science which relates to the processes of plant-life is called Vegetable Physiology.

The life of a plant is very different from that of an animal. Plants and animals, however, agree in having a limited term of existence—they are born, being produced from seed; they grow, become old, and die, having during their life produced others of their own kind to replace them.

Organs—Cells.—Plants and animals agree also in being entirely composed of *organs*. These organs are made up of other organs, and every plant or animal ultimately consists of *cells*, which are at first little globules, but often become extended into very various forms. The cells of a plant have at first a thin skin like a little bladder, containing a fluid substance, in which a kind of motion is kept up. Everything in plants and animals is formed from these cells, even the wood of plants and the bones of animals. A plant or an animal grows by adding cell to cell, changes also taking place in the cells already formed. One cell is added to another, or grows from another in a determinate manner, according to the nature of each particular kind of plant or animal, and of each particular part of it.

Earliest Stages of Plant-life—Germination of Seed.—A plant in the earliest stage of its existence, as it is formed in the parent plant, consists of a single cell, which is gradually developed into a *seed*. As the seed is matured, in all the higher kinds of plants, such as trees and flowering-plants, many cells are formed in it. In a flower, we find the rudiment of the *seed-vessel*, containing the rudiments of the seeds, which are called *ovules*,[1] from their resemblance to *little eggs*.—The rudimentary seed-vessel itself is called the *ovary* or *germen;* the term *ovary* signifying that it contains the little eggs or ovules, and *germen*, a Latin word, indicating its purpose as that part of the plant from which new plants are

[1] Latin *ovula*, a little egg.

to proceed. When the seed is placed in the ground, in favourable conditions of heat and moisture, it soon begins to *germinate*[1] or sprout. Changes take place within the seed itself, new cells are formed, and through a hole in the covering of the seed, not in general easily perceptible before, a little root is sent out, which descends into the soil to seek nourishment; whilst from the same part of the seed a shoot ascends into the air, and begins to develop leaves, by which also the plant seeks nourishment; for it is sustained not only from the soil through its roots, but from the air through its leaves, the leaves being organs of nutrition as much as the roots, and equally essential to life. The part of the seed which extends downward into the soil and forms the root, is called the *radicle*[2] or little root (*c*, fig. 72); the ascending part, which becomes the stem, and from which leaves, flowers, and fruit are developed, is called the *plumule*[3] or little feather (*b*, fig. 72), many plants, when they first spring from the ground, having somewhat the appearance which this term suggests.

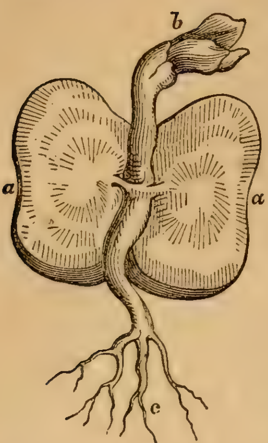


Fig. 72.—A bean beginning to grow, spread open.

Growth and Structure of Plants.—As plants grow, the stem of many divides and subdivides into branches, but there are others in which no such division takes place, and there are many, as primroses, lilies, and hyacinths, which send up no stem, but have only flower-stalks, such as spring from the buds of other plants, arising from the *crown of the root.* There are also plants which have neither stem nor leaves, nor even roots, but which imbibe their nourishment through their whole surface from the air or water in which they live, as lichens, fungi, and sea-weeds. In the very lowest and simplest forms of vegetation, nothing is to be found but a mere cell, or a number of cells variously grouped together, each cell, however, appearing to be an independent plant.

Cellular Tissue and Vascular Tissue.—Some portions of all plants, and the whole of some, consist of what is called *cellular tissue*—that is, of mere cells variously aggregated. Cellular tissue abounds in the soft and fleshy parts of plants; and some of these are often greatly developed and increased by cultivation, so as to render the plant more useful to man. The parts of plants used for food consist mainly of cellular tissue. Cells, however, often extend in particular directions as the plant grows, or numerous cells are combined into one, some part of the separating

[1] Latin *germinare*, to sprout.
[2] From Latin *radix, radicis*, a root.
[3] From Latin *pluma*, a feather.

membranes or *cell-walls* being absorbed; and at the same time the membrane which encloses the united cells thickens, by deposits taking place in its interior. Thus *vessels* are formed, which are closed tubes tapering to both extremities, and a substance called *vascular tissue*,[1] which is less soft and succulent than cellular tissue, and often becomes very tough and hard. Vascular tissue is generally found wherever strength is required, as in stems, the ribs of leaves, and the shells of nuts. A most important kind of vascular tissue is *woody tissue*, which in shrubs and trees becomes compacted into *wood*, the vessels being filled up by the deposits which take place in them, so that great solidity is attained. Not only is the wood of many trees of great value to man, but woody tissue, which never becomes compacted into wood, is also of much importance, as affording the fibrous materials of which cordage and clothing are made. Another kind of vascular tissue consists of *spiral vessels*, which are tubes of extreme fineness, sometimes not more than one three-thousandth part of an inch in diameter, coiled up within the young shoots and leaf-stalks of plants. These spiral vessels may be pulled out to a great length. If a young shoot or leaf-stalk of a geranium be broken, and the parts gently pulled asunder, the spiral vessels will be seen, delicate as the threads of a cobweb. Their great number, however, and their closely compacted coils, add to the strength of the shoot or leaf-stalk, whilst they contribute also to the circulation of its sap.

Organs.—The organs of which plants consist are divided into two classes —*Nutritive Organs* and *Reproductive Organs;* the former being those which are essential to the life of the individual plant, the latter those which have for their purpose the perpetuation of the race. The nutritive organs are the root, stem, and leaves; the reproductive organs are the flowers and all organs concerned in the production of seeds.

Nutritive Organs of Plants.

The Root.—The *root* not only serves the purpose of drawing nourishment from the soil, but also that of fixing the plant in its place, and it has often been remarked with admiration that trees growing in exposed situations send out more numerous roots than those which grow in sheltered places, as if to anchor themselves more firmly, and to secure themselves against storms.

Roots are often branched, and the branching is repeated again and again, particularly in hard and woody roots, which are divided at last into fine fibres. Softer roots are often quite unbranched, as in the hyacinth. The extremities of roots consist of loose cells, forming a minute spongy

[1] From Latin *vasculum*, a little vessel.

mass called a *spongiole* or little sponge, and by these cells the fluid nourishment of the plant is imbibed. Animal and vegetable membranes have the property of allowing fluids to pass through them, not by any special pores, but at all parts, through minute interstices in their whole structure; and when the membrane is very thin, as that is which forms the cells of a spongiole, and the fluid on one side of it differs considerably in density from that on the other, an exchange pretty rapidly takes place by what is called *osmotic action.*[1] This may be exemplified by filling a bladder with brine from salted meat, and placing it in a vessel full of pure water, when much of the salt of the brine will soon be found to pass through the bladder into the water by which it is surrounded. The animal substances contained in the brine will, however, remain in the bladder, which will receive a quantity of water greater than that of the substances which have passed out. Osmotic action is carried on to a great extent in nature, the cells both of animals and plants thus imparting their contents to those which are in contact with them, so that a motion of fluids is kept up even where there are no proper veins or tubes, and changes are at the same time effected in the fluids themselves. And thus it is that the roots of plants take in nutriment, whilst they are also continually giving forth substances which the plant may be said to desire to be quit of, and the continual growth of the root pushes forward the spongiole into a new place, where it finds fresh soil. The soil in which a plant grows therefore undergoes a twofold change, being deprived of the substances most beneficial for the nourishment of the plant, and more or less filled with others which are specially unsuitable to it; but these are often very suitable for other plants; and thus the farmer finds a rotation of crops more advantageous than a continual repetition of the same kind of crop on the same land.

Roots are covered with a bark like that of stems; and the roots of some plants, if by accident or design exposed to the air, produce buds from which shoots or branches proceed. The roots of many plants extend underground and send up shoots. Many plants also send forth roots from the stem or branches, when these are brought into contact with the soil, or partially buried in it; and advantage is taken of this to propagate some kinds of trees and shrubs by *cuttings,* which soon produce roots when planted in moist earth, or by *layers,* which are branches bent down and partially covered with earth, but not separated from the parent plant till the new roots are formed. Some plants, in their ordinary growth, send forth roots from the stem or branches, which, as they elongate, seek the ground, and form new stems or props to the stem, adding also to the supply of nourishment from the soil. A remarkable

[1] From Greek *osmos,* impulsion.

example of this is seen in the banyan-tree of India, from the wide-spreading branches of which roots descend straight to the ground, so that a vast canopy of branches and leaves is formed, supported by numerous

Fig. 73.—The Banyan-tree.

tall columns. A banyan-tree has been described having no fewer than 350 stems equal to large oaks, and more than 3000 smaller ones, covering a space sufficient to contain 7000 persons.

Tubers and Bulbs.—Some soft roots swell very much in favourable circumstances, storing up in their cells nourishment for the future wants of the plant. The swelling takes place in various forms. The turnip and the carrot afford instances of two of the most common forms. The *tubers*[1] of the potato are not properly parts of the root, but short and thick subterranean stems, the *eyes* being buds ready to send up shoots into the air in the spring of the following year, and the substance of the tuber being a provision for the nourishment of these shoots, until they become independent of the parent plant. *Bulbs* also, as those of the onion, the lily, and the hyacinth, are not really parts of the root, although we familiarly speak of such plants as *bulbous-rooted*, and of the potato and the Jerusalem artichoke as *tuberous-rooted*. A bulb is, in fact, a subterranean bud, and the true stem is the very short hard part at its base from which the roots spring.

Stems.—Some plants have their stems entirely underground; not only those which have extremely short stems, and are commonly described as *stemless*, but some also in which the stem extends to a considerable length. A root-like stem, creeping underground, or along the surface of the

[1] Latin, 'a swelling,' from *tumeo*, to swell.

ground, sending down roots into the soil, and sending up shoots into the air, is called a *root-stock*. Examples may be seen in the yellow iris and in Solomon's seal. Whilst some plants have strong and erect stems, capable of sustaining all the weight of their branches and leaves, the stems of others are slender and weak, trailing along the ground, or depending upon other plants for their support. Of those which seek the support of other plants, some are provided with tendrils, by which they lay hold of them, and others twine around them. The pea is an instance of a *climbing plant*, and its tendrils coil in an admirable manner around the branches to which it clings. The scarlet runner is a twining plant: it has no tendrils, but its long stem twines round any pole or branch with which it meets. It is remarkable that twining stems always twine in a particular direction, some from right to left, others from left to right. The scarlet runner twines from right to left, the hop and the honeysuckle twine from left to right. Climbing and twining plants greatly abound in tropical countries, and contribute much to the prodigious density of vegetation in the forests, some of them ascending to the tops of the most lofty trees, and falling down again from their high branches, rich in foliage, and often also in flowers of the greatest beauty, or binding tree to tree, so that the forest becomes impenetrable.

Soft stems are called *herbaceous*, and the plants to which they belong are called *herbaceous plants*, in contradistinction to trees and shrubs, which are *woody plants*. Herbaceous stems are often annual—that is, their existence is limited to a single year. They rise from the ground in spring, and die on the approach of winter, even although the root may survive. Woody stems subsist during the whole life of the plant.

Buds and Branches.—Stems, as they grow, produce buds. The stem always terminates in a bud; and in some plants, as in the greater number of palms, this is the only bud. In this case, there are no branches, what are often spoken of as the branches of palms being really leaves of extraordinary magnitude. Branches proceed from lateral buds. The buds of some plants arise only from certain well-marked points of the stem, called *nodes*[1] or knots, which appear as joints, of which a strongly marked example is found in the bamboo; and although this cannot be so clearly observed in other plants, yet in all a certain rule is followed, so that the buds do not appear irregularly scattered, but arranged according to a definite method. Thus the arrangement of leaves is different in different plants; in one they are in pairs on opposite sides of the stem, in another they spring from opposite sides alternately, while in some they are found in whorls. They are very generally arranged in a kind of spiral manner around the stem. A similar diversity of arrangement

[1] Greek *nodos*, a knot.

appears in the branches, which spring from the *axils*[1] of leaves, every plant having its own peculiar and characteristic mode of branching, which, by giving diversity of aspect to trees, greatly contributes to the beauty of nature. Buds remain dormant during winter, the tender parts being protected from the frost by the scales with which they are covered. In spring, they begin to grow, when the sap ascends in the tree. Many buds, however, remain always dormant, especially on the lower parts of the stem and branches, the strength of the plant being directed to the production of branches and leaves in its upper and outer parts; but if a branch is cut off over above a bud which it has thus seemed to neglect, the bud at once begins to grow, and to send forth a shoot in place of that which has been removed. Some plants send forth branches of peculiar kinds. The *runner* of a strawberry is a kind of branch, although the plant is one of those in which the stem is scarcely developed. Such a branch, producing a bud at its extremity, serves for the extension of the plant over the surface of the ground, the bud soon sending down roots, and becoming capable of independent existence.

Structure of Stems.—There are great differences in the structure of stems, and, according to these, plants are arranged into different classes, which differ also very much in other important characters. Three modes of structure are distinguished, and stems are accordingly described as *exogenous*, *endogenous*, or *acrogenous*, terms which are also applied to the plants to which they belong.[2]

Exogenous Stems.—Exogenous stems are those which have a *bark* distinct and separable from the wood, and in the centre of the stem a *pith*, which sends out branches, called *medullary rays*,[3] through all parts even of the hardest wood. The medullary rays keep up a connection between the pith and the soft growing part immediately under the bark, and are essential to the nourishment of the wood. Exogenous stems increase in thickness by new layers of *vessels* formed under the bark, which gradually harden into wood; and the layers produced year after year are very often so distinctly marked, that the age of a tree may be pretty accurately computed by counting the number of them exhibited in a transverse section of its stem. All the trees and shrubs to be seen in Britain, and very

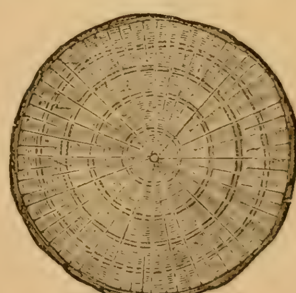


Fig. 74.—Transverse Section of Exogenous Stem.

1 The hollows where the branches unite with the stem, from Latin *axilla*, the armpit.

2 These terms are derived from the Greek words *gennaō*, to produce, *exō*, outwards, *endon*, inwards, and *akros*, highest; and they are employed as indicating the manner in which these different kinds of stems grow.

3 From Latin *medulla*, pith.

many of the herbaceous plants, are exogenous. In herbaceous stems, the medullary rays are generally large, and the more solid part of the stem consists of *vascular bundles*, arranged around the pith, and these bundles, when cut across, appear somewhat wedge-shaped, becoming broader outwards. The arrangement is beautifully regular. In trees and shrubs, the medullary rays generally become very fine as the wood hardens, so that they do not much affect its solidity.

The *pith* consists of cellular tissue.—The *wood* consists of vascular tissue, and chiefly of long vessels, closed at the ends, which, as they become old, are gradually filled up with solid matter. The wood nearest the pith is harder than the younger wood near the bark, and in some trees is also very different in colour. The matured wood is called *heart-wood* or *duramen*;[1] and the soft wood, which forms the outer part of the stem, is called *sap-wood* or *alburnum*.[2]—Next to the wood, on the outside, is a layer of soft cells, called the *cambium layer*, formed in a mucilaginous fluid, called *cambium*,[3] which may be best observed in young shoots, and in spring when vegetation is most active. From the cambium layer, the new layer of wood is formed, and the necessary increase is also made to the bark.—The bark, in young stems or branches, consists of mere cellular tissue, but vessels are afterwards formed in the inner portion of it, which often become long and strong fibres. The valuable fibres of flax and hemp belong to the inner bark of these plants; and bast mats are made of the inner bark of the linden or lime tree. There is an Indian tree of the bark of which sacks are made by merely stripping the bark from the wood, which is done by beating it till it comes off readily, as boys make 'plane-tree' whistles. The *inner bark* is also called the *bast*. Its Latin name is *liber*, which is also the Latin for 'a book,' this bark having been used for writing on before the use of paper or parchment was known. The outer part of the bark is entirely cellular, but consists of two layers, easily to be distinguished. The outermost of these is that which, in the cork-tree, increases to a great thickness, affording us the substance known as cork. The bark itself is surrounded by an integument, called the *epidermis*, the use of which seems merely to be the protection of the whole: in old stems it is thrown off, although it is always to be found in young and tender shoots.

Endogenous Stems.—Endogenous stems have no pith and no bark. The outer part of the stem may indeed be somewhat different from the rest, and have the appearance of a bark, but it cannot be separated from the wood like the bark of an exogenous tree. As an endogenous plant grows, the stem increases in thickness, not by the addition of layers on the

1 From Latin *durus*, hard.
2 From Latin *albus*, white.
3 Low Latin, 'nutriment,' from Latin *cambio*, to change.

outside, but by the formation of new bundles of vessels in the centre, which push out those previously formed, as long as they are soft enough; but when they are thoroughly hardened, this no longer takes place, and the stem increases in length without further increase of thickness.

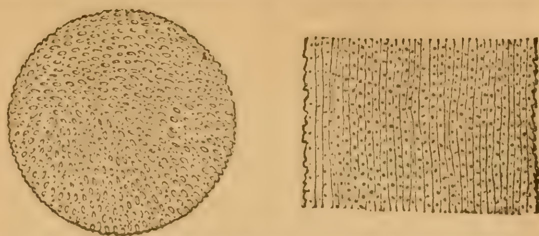


Fig. 75.—Transverse and Vertical Sections of Endogenous Stem.

Thus palms are, in general, of almost uniform thickness from the root to the crown of leaves, and the outer part of the stem is often very hard, whilst the central part is soft and spongy, and amongst its cells there is often a great deposit of starch, which, in the sago palms, is so abundant as to be of economical importance. Palms are almost the only endogenous *trees*, and no endogenous tree is found anywhere but in the warmer parts of the globe. Endogenous plants, however, abound in all countries, and amongst them are all the grasses and all the plants which have bulbs. Endogenous stems are very often unbranched, producing no buds but the terminal bud. The great terminal bud of a palm resembles a cabbage in size, and also in quality, so that palms are often cut down for the sake of it. It is called the *palm cabbage;* and some kinds of palm, in which it is particularly good for the table, receive the name of cabbage palms. The rapid growth of many endogenous stems ruptures the central cells, and thus a hollow stem is produced, as in grasses.

Acrogenous Stems.—Acrogenous stems resemble endogenous stems in having neither pith nor separable bark, but differ from them in their mode of growth, all the bundles of vessels, or fibres, being developed at once, so that the stem increases only by additions at the summit. The acrogenous stem has no branches, but produces a crown of leaves; so that a tree-fern, which is the only kind of acrogenous *tree*, has a general resemblance to a palm. In the ferns of Britain and other temperate countries, the stem creeps along the ground as a root-stock.

Fig. 76.—Transverse Section of Acrogenous Stem.

Fig. 77. Tree-fern.

Leaves.—Leaves are most important organs of plants. They expose a great surface to the air, imbibe what the plant requires for its nourishment, and give out what is no longer useful to it. They are of very great importance in the system of nature, the gases which the leaves give out being generally those most needful for the support of animal life, so that the multitude of leaves on the face of the earth keeps the air fit for the use of animals, whereas it would otherwise become such that animals could no longer breathe it and live.

Leaves are curiously folded or rolled up in the bud before they are developed. In some plants, they are folded by the midrib, the two halves of the leaf lying together; in others, they are folded in a fan-like manner; in some, they have their edges rolled inwards, in others, outwards; and in some, they are rolled together in a single coil. The different modes in which the leaf is formed in the bud are characteristic of different plants. The cherry and the plum are trees nearly allied, but the leaves of the cherry are folded together in the bud, while those of the plum are rolled up.

The expanded part of a leaf generally faces the sun, the influence of light being necessary as well as that of air. This expanded part is called the *blade of the leaf.* The leaf, however, is often supported by a stalk, called the *leaf-stalk* or *petiole*,[1] which in trees and shrubs is often woody, and in some, particularly in palms, becomes thick and hard like a branch. Leaves which have no leaf-stalk are called *sessile*,[2] because they seem to *sit* upon the stem or branch. In many plants, the leaves which spring from the crown of the root differ very much from those which are produced higher on the stem. Thus, the common harebell has root-leaves nearly round, whilst those of its stem are very narrow. The leaf-stalk divides into branches, which form the *ribs* or *veins* of the leaf, and give it the necessary strength. In endogenous plants, the veins of the leaf are in general nearly parallel, running unbranched throughout the whole length of the leaf, as may be seen in grasses; in exogenous plants they break into branches, which spread in various directions, and are again and again branched, so as to form a kind of network, as may be seen in the leaf of the elm or the primrose. This difference in the leaves characterises these two classes of plants as much as that in the structure of the stem. The leaves of acrogenous plants have generally forked veins.

In some plants, the leaf-stalk is broad, and the blade of the leaf at its extremity is very small, or scarcely exists, as in many species of *Acacia.* In this case the leaf-stalk serves the purposes which are ordinarily served

[1] 'The little foot,' from Latin *pes, pedis*, the foot.

[2] From Latin *sessilis*, sitting, from *sedeo, sessum*, to sit.

by the blade of the leaf. Some leaves are thick and fleshy. The forms of leaves are very various, and many are divided into lobes or segments. A leaf much divided into lobes may yet consist altogether of one piece; and a leaf which consists of one piece, whether lobed or not, is called a *simple* leaf. Many leaves, however, are *compound*—that is, they are made of a number of pieces, the leaf-stalk branching by joints, and sometimes branching again and again, each branch or branchlet bearing a separate blade, called a *leaflet*. Such leaves are called *pinnated*,[1] when the leaflets are arranged on opposite sides of the stalk, as in the ash or the laburnum. A leaf may be *bipinnate*—that is, twice pinnate—or the leaf-stalk may be still more subdivided. In some compound leaves, the leaf-stalk divides into three branches, as in the clover or trefoil; in others it sends off a number of leaflets in a radiating manner from its extremity, as in the horse-chestnut.

Stomata.—In the epidermis of leaves there are minute openings, called *stomata*, a Greek word signifying *mouths*. These are also found in the epidermis of young shoots, and of other green parts of plants. They serve for the admission of air as the plant requires it, and for the exhalation of what it gives off into the air; and leaves have therefore sometimes been called the *lungs* of plants. The stomata are very small, and can only be discerned by the aid of a microscope. There are sometimes 160,000 or more in a square inch of surface; and in those plants which have fewest and largest stomata, there are about 200 in a square inch.

Circulation of Sap.—Plants have no organ resembling the heart of an animal, and the circulation of sap which takes place in them is of a very different nature from the circulation of blood. The sap imbibed by the roots ascends through the vessels of the stem, and passes from vessel to vessel by osmotic action. In plants wholly formed of cellular tissue, the sap seems to proceed in any direction from one cell to another, till the whole substance of the plant is permeated; in vascular plants, particular parts of the plant appear to be chiefly concerned in this process, which, however, is very imperfectly understood. It is known that the sap circulates most abundantly through the youngest layers of wood, whilst in the old and thoroughly hardened layers it almost entirely ceases, and these may therefore almost be regarded as having ceased to live, and as useful to the plant only by giving strength to its stem. The sap reaches every part of the plant, being conveyed through the finest leaf-stalks and flower-stalks, and penetrating the most delicate parts of the flowers. In the leaves and other green parts, it is modified by the action of the air and light, and afterwards descends again to the root, which it is generally believed to do through vessels in the bark, giving off supplies of nourishment

[1] From Latin *pinna*, a wing.

to every part of the plant as it descends; for the nourishment of the organs of a plant is supposed to be derived more from the sap that has been elaborated in the leaves than from the ascending sap in its original state. The rise of the sap in spring is one of the unexplained wonders of nature; it cannot be ascribed to the mere increase of heat, for it begins in many plants during the very coldest weather of winter. They have had their period of rest, and their time of activity comes again. Plants need rest as well as animals. A plant continually forced to grow, by artificial application of heat and moisture, soon ceases to live; and gardeners well know the necessity of allowing rest to hothouse plants. The plants of tropical countries often have their periods of rest and activity determined by the wet and dry seasons, which are to them as summer and winter.

Reproductive Organs of Plants.

The reproductive organs of plants are very different in the lower and the higher kinds. Of some of the lowest kinds we know nothing more than that they increase by the addition of one cell to another, and are propagated by the separation and diffusion of these cells; although it is probable that even these plants produce seeds or spores, by which they are multiplied. Their very minute size, however, makes it difficult to investigate the processes of their life. In the highest kinds of plants, the reproductive organs are the *flowers*, and the fruit produced by them.

Flowers—Inflorescence.—The arrangement of the flowers upon a stem or branch is called the *inflorescence*[1] of a plant. In some plants, each flower arises from the root on a separate stalk; in others, it arises in like manner from the stem or from a branch. In some, many flowers are produced on a single stalk, and the upper part of a stem or branch often becomes itself a flower-stalk, its leaves becoming modified into *bracts*,[2] which are placed under each flower or each division of the flower-stalk. Bracts sometimes resemble the ordinary leaves of the plant, but are very often much smaller and less divided, and are sometimes membraneous and dry, sometimes of colours very different from the leaves. In some plants, the bracts are large, and in the bud enclose a stalk which produces numerous flowers. The bract in this case is called a *spathe*,[3] and the flower-stalk a *spadix*.[3] An example is seen in the wake-robin, and palms have this form of inflorescence. In some palms, the spathe is very large, thick, and leathery, so that it is often made into a sack or bag; and there are palms which have a spadix twenty feet long, and bearing more than 200,000 flowers.

1 From Latin *in*, upon, and *floresco*, to flower.
2 From Latin *bractea*, a thin plate of metal, gold-leaf.
3 From Latin *spatha*, a broad leaf.

When flowers grow from an elongated flower-stalk without distinct stalks of their own, or when their separate stalks are very short, they form a *spike*, as in the plantain or rib-grass; when the separate stalks are of notable length, we have a *raceme*,[1] as in the hyacinth. Both spikes and racemes are often compound by the branching of the principal stalk. Compound spikes sometimes have their branches or *spikelets*, closely compacted into a *head of flowers*. Spikes of a close form, having a scaly bract under each flower, are called *catkins*.[2] When the lower flowers of a raceme are supported on longer stalks than the upper, so that all the flowers are nearly on a level at top, as in the hawthorn, we have a *corymb*.[3] When all the branches of a raceme spring from nearly the same point, and diverge in a radiating manner, they form an *umbel*.[4] An example of the umbel may be seen in the cowslip, but this form of inflorescence is particularly characteristic of a great order of plants, therefore called *Umbelliferæ* or umbel-bearers, of which the carrot, the cow-parsnip, and the hemlock are familiar examples. In all these forms of inflorescence, the first flowers which expand are the lowest or outermost. There are plants, however, in which the first flowers produced are the most central. In this case, the flowers are often produced on stalks which grow up together in nearly equal length, and form what is called a *cyme*,[5] an example of which may be seen in the elder.

Flowers—Parts of the Flower.—Flowers are produced from buds as leaves are. The parts of a flower are, in fact, leaves changed as to their form and use, but produced and arranged after the manner of leaves; and their true nature is shewn by their sometimes becoming leaves again in what are called *monstrosities* of plants, which often occur when a plant receives excess of nourishment through cultivation. They arise from the stalk of the flower, as leaves arise from the stem, but form definite groups very distinct in character and use. These groups are generally whorls, even when the leaves of the plant are not whorled. The first or outermost whorl (*g*, fig. 78) forms the *calyx* [Greek, a cup], and commonly consists of small green leaves called *sepals*, which are often united so as to form a kind of cup. The use of the calyx seems to be the protection of the more tender parts of the flower, and it encloses them all when in bud. The second whorl of leaves, which may either be quite distinct, or may unite into a cup, bell, or tube, is the *corolla*[6] (*h*, fig. 78), generally the most beautiful part of the flower; the leaves which form it, called *petals*,[7] being delicate and finely coloured. The calyx, however, sometimes assumes an appearance similar to that of the corolla; and in some plants, these whorls grow so closely

[1] From Latin *racemus*, a cluster of grapes.
[2] From the resemblance of a cluster to a cat's tail.
[3] From Latin *corymbus*, a cluster of fruit.
[4] 'A little shade,' from Latin *umbra*, a shade.
[5] From Latin *cyma*, a sprout.
[6] Latin, 'little crown,' diminutive of *corona*, a crown.
[7] Latin *petalum*, a leaf.

together as to be almost one, and resemble one another very closely, as in the crocus. In this case, they are not generally distinguished by the names of calyx and corolla, but receive together the name of *perianth*,[1] because they surround the essential parts of the flower. These parts are the *stamens*[2] and *pistils*.[3] From an analogy with animals, the stamens are called the male organs, and the pistils the female organs of fructification.

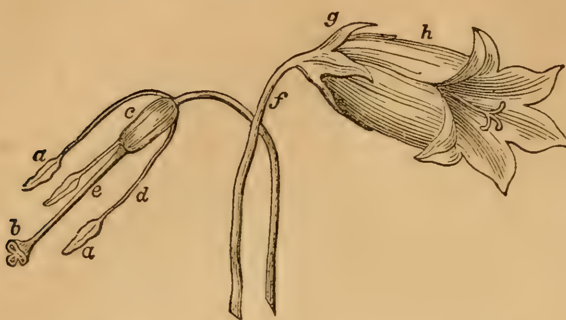


Fig. 78.—Flower of Campanula: *a*, anther; *b*, stigma; *c*, germen; *d*, filament; *e*, style; *f*, flower-stalk; *g*, calyx; *h*, corolla.

The stamens form the whorl next within the corolla; the pistils are the innermost of all, and are the final extension of the stem or stalk from which the flower grows. The pistils contain the ovules, which, when matured, become the seeds. A pistil is sometimes formed of one modified leaf, and sometimes of several, more or less united. Each leaf which enters into the formation of the pistil is called a *carpel*,[4] and each carpel has its own ovules. The lower part of the pistil is the *germen* or *ovary* (*c*, fig. 78), in which are the ovules; from this rises the *style*[5] (*e*, fig. 78), which is crowned by the *stigma*[6] (*b*, fig. 78). The style is often very slender, although in some flowers it is thick and stout. The stigma also assumes very various forms; it is sometimes broad and large, sometimes nothing more than the mere point of the style. The style is sometimes altogether absent, and the stigma rests immediately on the summit of the germen. The only use of the style is as a tube to communicate between the stigma and the germen. The stamens are ranged around the pistil. In some plants, they are few in number; in others, they are very numerous. Those plants which have few stamens have a certain number of them, as they have also a certain number of sepals and of petals; and it very often happens that there is a correspondence in these numbers, so that some plants are *dimerous*, some *trimerous*, some *tetramerous*, and others *pentamerous*.[7] The crocus is an example of a trimerous flower; the primrose is a pentamerous flower. A stamen consists of two

1 From the Greek *peri*, around, and *anthos*, a flower.

2 Latin *stamen*, a thread, a fibre.

3 So called from their likeness to the *pestle* of a mortar.

4 From Greek *karpos*, a fruit.

5 From the Greek *stylos*, a pillar.

6 Greek, 'a mark.'

7 From the Greek *meros*, a part, *dis*, twice, *tres*, three, *tetra*, four, and *penta*, five.

parts, called the *filament*[1] (*d*, fig. 78), and the *anther*[2] (*a*, *a*, fig. 78). The filament is the modified stalk of the leaf, the anther its blade. The filament is generally slender, as the name indicates; in some flowers it is extremely so, but in others it is thick and stout, and in some it is altogether absent; whilst the anthers are sometimes produced on the pistil itself, which is a peculiarity of orchids. The anther is the essential part of the stamen; the filament serves merely for its support. The anther is attached to the filament in various ways, sometimes firmly, or even as covering the mere extremity of its surface, and sometimes by an extremely slender neck, so as to be liable to be shaken by the slightest breath of wind, or by the touch of the smallest insect. The anther, when matured, which it is when the flower is in full perfection, produces *pollen*.[3] Pollen is a fine dust, which, when examined by the microscope, is seen to consist of minute cells. The anther consists of two lobes, corresponding to the two sides of the blade of a leaf, and these both produce pollen. Pollen is produced in cells or cases, which burst and scatter it. It is essential to the fecundation of flowers—that is, to make them productive of seed; and in order to this, it must be applied to the stigma, through which the minute pollen grains find their way to the germen and its ovules. The fecundation of plants is often very much assisted by insects, which stir the stamens, and set the pollen afloat in the air. In some plants, the stamen has a peculiar property called *irritability*, so that when the filament is touched, it moves, and closes upon the pistil, as may be seen in the barberry, the stamens of which can readily be made to move in this way by touching them near the base with the point of a needle. The stamens and pistils are ordinarily found in the same flower, arranged as already described, the stamens forming the whorl which immediately surrounds the pistils: such flowers are called *hermaphrodite*.[4] In many plants, however, there are flowers which have stamens only, and other flowers which have pistils only, and the flowers are then described as *male* and *female* flowers. The pollen of the male flowers is often extremely abundant, and is carried about in the air, as may be seen in the hazel, from which it may be driven off in clouds by shaking the branches at the time of flowering. The male flowers of the hazel are in long yellowish-white catkins, which have a very beautiful appearance as they hang from the branches in early spring, before the leaves are expanded; the female flowers are small and red, situated at the tips of buds. Plants which have the stamens and pistils in different flowers on the same plant, as the

[1] From Latin *filum*, a thread. [2] From Greek *anthos*, a flower. [3] Latin, 'dust.'

[4] That is 'of both sexes.' The word is derived from the mythological story of *Hermaphroditus*, the son of *Hermēs* (Mercury) and *Aphroditē* (Venus), who, when bathing, grew together with a nymph into one person.

hazel, are called *monœcious*;[1] but there are also plants which have the male and female flowers on separate plants, as the date-palm and the hemp, and these are called *diœcious*.[2] Flowers which have both stamens and pistils are called *perfect* flowers, because all the essential parts of the flower are found in them. In some such, however, the calyx or the corolla is awanting; and there are flowers which have none of these envelopes, but consist of stamens and pistils only: such flowers are described as *naked*. A flower which has calyx, corolla, stamens, and pistils, is called *complete*.

The parts of a flower are variously arranged. The leaves of the calyx and corolla, the sepals and petals, are sometimes opposite to one another, sometimes alternate, and a similar diversity appears in the inner whorls. Not unfrequently there are two or more stamens for each petal, and sometimes many; and the stamens are sometimes in bundles, as if many were formed by the division of a single leaf. Some of the whorls which form a flower often consist of a number of parts, which is a multiple of the number that characterises the flower, making it trimerous, pentamerous, &c.—as six instead of three, or ten instead of five. This regularity of numerical arrangement is called the *symmetry* of flowers. A flower in which the parts of each whorl are equal and similar, or nearly so, is called a *regular* flower, as the flower of the crocus or primrose. Many flowers, however, are irregular. Sometimes one leaf of the calyx is more developed than the rest, and assumes a different form; this more frequently occurs in the corolla, and sometimes in the stamens. The flower of a true geranium is regular; but the flower of a pelargonium, which is very nearly allied to a geranium, and is often called by that name, is irregular, the five petals of the flower appearing as two upper and three lower petals, with some difference of size and form. In the flowers of many orchids, irregularity may be said to be carried to its extreme. Some irregular flowers assume peculiar forms, and some of these are characteristic of certain orders of plants. Thus, the form called *papilionaceous*,[3] because of its resemblance to a *butterfly*, prevails generally in an order of plants containing a multitude of species, and producing their seeds in pods, of which the pea is an example.

Fruit.—The matured carpels of the flower form the *fruit* of a plant, and the matured ovules the seeds. Sometimes the fruit consists only of a single carpel, which contains only one seed, or a number of seeds; sometimes of a number of carpels belonging to the same flower, which are either separate or closely united together, so as to form one seed-vessel, or *pericarp*.[4] In pines and firs, there is no seed-vessel, but the seeds are protected by scales. The fruit is sometimes formed not merely

1 From Greek *monos*, one, and *oikos*, a house.
2 From Greek *dis*, twice, and *oikos*, a house.
3 From Latin *papilio*, a butterfly.
4 From Greek *peri*, around, and *karpos*, fruit.

of the pistil, but of other parts of the flower united with it. Thus, the calyx, which in some plants falls off during or immediately after flowering, is permanent in others, and remains attached to the fruit. The whole of a ripe fruit is often dry and hard, the softest part being the seed itself; but in other fruits, some part enlarges and becomes succulent, as in the apple, pear, plum, &c.; and a soft pulpy substance is formed in the interior of some fruits, as the gooseberry, grape, and orange. When the fruit is ripe, it often opens to scatter the seeds, which takes place in a great variety of ways, some of them very curious. Soft fruits, however, fall off entire when ripe, and the seeds are set free by the decay of the soft parts, or when they are eaten by birds or other animals, by which they are often carried to a distance so that the plant may be produced in a new situation. Among the provisions of nature for the dispersion of seeds are wing-like appendages with which some are furnished, so that they are readily wafted about by the wind. The down attached to the seed of a thistle is an appendage of which this is the obvious use. It is called the *pappus*,[1] and assumes various forms. In the dandelion, it consists of a stalk, from the summit of which hairs radiate; and the pappus stalks produced from a head of flowers are so regular in length, that their hairs, spreading out and touching each other, form a beautiful globe. The pods of some plants, as the broom, burst with considerable force when ripe, so as to fling the seed away from the parent plant, and in a warm summer day, the sound of the cracking of the pods may be heard at a considerable distance. The seed-vessels of the poppy exhibit a very different provision for the accomplishment of the same object. They resemble little urns, which have a row of small holes around them, just under the top; and the seeds, which are very small and very numerous, are scattered through these holes when the stem of the plant is shaken by the wind, as pepper is shaken out of a pepper-box. The great seeds of the cocoa-nut palm are wafted by the waves and currents of the ocean from one tropical coast to another, protected from the water by their thick husk and firm shell.

A fruit is generally formed from the pistil of a single flower, but the pistils of a number of flowers growing close together sometimes combine to form one fruit, as in the pine-apple, mulberry, and fig, the fleshy parts coalescing together.

Different kinds of Fruits.—There are so many different kinds of fruits, that a complete enumeration and description of them cannot be attempted here. Only a few of the most common and important can be noticed. A pear or an apple is a *pome*, so called from the Latin *pomum*, an apple, and is formed of two or more carpels. In the centre are cartilaginous or bony cells, containing the seeds, with a fleshy mass around them. A

[1] From Greek *pappos*, down.

plum, cherry, or peach is a *drupe*.[1] Fruits of this kind, popularly called stone-fruits, have one seed, or sometimes two seeds, surrounded by a hard shell, and around this is a fleshy covering. A *berry* is a fruit having the seeds amidst a fleshy or pulpy mass, as in the gooseberry and currant. The grape, the orange, lemon, &c., and the melon, cucumber, &c., afford examples of kinds of fruit closely allied to the true berry. A *pod* or *legume*[2] is a dry fruit, opening along two edges, so as to split into two halves, to which the seeds are attached. The name *pod* is also often given to the *silique*,[3] which differs from the legume in having a central piece, from which the valves part when the fruit is ripe, leaving the seeds attached to it, as may be seen in the kale, the turnip, the wall-flower, and all the large order of plants to which these belong. A *capsule*[4] is a dry fruit, which assumes a very great variety of forms in different plants, and sometimes opens along its whole length by valves, sometimes along part of its length from the top, so that, when open, it is toothed; sometimes by pores, as in the case of the poppy already noticed; and sometimes by throwing off a lid. A *nut* is a dry one-seeded fruit, with a hard shell which does not open.

Seed.—A seed usually consists of a nucleus or kernel, protected by integuments. The nucleus is often entirely formed of the *embryo* destined to become a new plant; and in this case, the whole store of matter necessary for the nourishment of the young plant in the commencement of its growth is contained in the embryo itself; but in many seeds there is a separate store of matter for this purpose, called the *albumen*,[5] which also forms part of the nucleus. The presence or absence of the albumen is a distinguishing character of many kinds of plants. The albumen is sometimes so large that the embryo forms only a small part of the seed; sometimes it is horny and hard, as in the vegetable ivory, a species of palm; sometimes it is farinaceous, as in wheat and other corn-plants; sometimes it is rich in oil, as in the poppy. The structure of the embryo itself does not depend upon the presence or absence of albumen. When we take off the integument of a pea or of a bean, seeds that have no albumen, the embryo is at once fully exposed to view, and we find it to consist of two lobes, united together at one point, from which the radicle and the plumule are to spring, the same point that the seed itself grew from, and by which it was attached to the parent plant. These lobes are called *seed-leaves* or *cotyledons*[6] (*a, a*, fig. 72, page 108), and in some plants,

1 From Greek *drupetēs*, quite ripe, from *drys*, a tree, and *piptō*, to fall.

2 Latin *legumen*, from *lego*, to gather, so called because the seeds are *gathered* or attached to only one suture or seam.

3 Latin *siliqua*, a pod.

4 Latin *capsula*, a little case, diminutive of *capsa*, a case.

5 A substance like the *white* of an egg, from Latin *albus*, white.

6 Greek, 'a cup-shaped leaf,' from *kotylē*, a cup.

as the scarlet runner, they come above ground when the young plant begins to grow; in others, as the bean and pea, they remain underground. Cotyledons exhibit a great variety of forms, and are sometimes wrinkled, curved, folded, or twisted. Those of the potato are spiral. Cotyledons are sometimes split into parts, as in firs, so that a seed appears to have many cotyledons instead of two. Plants of which the seeds have two cotyledons are called *Dicotyledonous*, from the Greek *dis*, twice. Those of which the seeds have only one cotyledon are called *Monocotyledonous*, from the Greek *monos*, one. These terms designate two great classes of plants, which include all the higher kinds of plants; but the lower kinds have an embryo entirely cellular, which is called a *spore*,[1] and gives forth a new root or stem from any part of its surface, according to the circumstances in which it is placed, and not necessarily from a particular point, as is the case in a monocotyledonous or dicotyledonous seed. Such plants are designated *Acotyledonous*, from the Greek privative *a*. There is a remarkable correspondence between the structure of the seed and the structure of the stem, so that *exogenous* plants are *dicotyledonous*, *endogenous* plants are *monocotyledonous*, and *acrogenous* plants are *acotyledonous*, and into these three great classes all plants are divided.

Classification of Plants.

About 120,000 species of plants are known, some of them so minute, that they are mere objects of microscopic examination, while others are of vast magnitude. The great object of botanists in their systems of classification is to exhibit the scheme of nature itself; and this is in a great measure accomplished by the division of plants into the three great classes just mentioned. Plants which have much agreement in structure and characters, are grouped together as forming one *order*, and those in which the resemblance is still closer as forming one *genus*.

Acrogenous Plants.—Of the lowest class of plants, known as *Acrogenous*, *Acotyledonous*, or *Cryptogamous*,[2] which have no flower, the lowest of all are found in the order *Algæ* [Latin, 'sea-weeds or water-weeds']. These abound both in the sea and in fresh water in all parts of the world. Some sea-weeds attain a great size, exceeding in length the tallest forest trees. They have no root, but are merely attached by their base to rocks, imbibing all their nourishment from the water in which they float. Some of the *Algæ* are used for food, as *dulse* and *carrageen* or *Irish moss*. Some of the larger sea-weeds are valuable as yielding *kelp*, which is obtained by burning them. Kelp, the ashes of sea-weed, contains a large

[1] From Greek *sporos*, seed.

[2] So called from their fructification being concealed, from Greek *kryptos*, concealed, and *gamos*, marriage.

quantity of soda, and was formerly much used in the manufacture of glass.

Fungi[1] are another order of the lowest kind of plants. Of this the mushroom is an example. All the *Fungi* are short-lived, they grow very rapidly, and soon decay. They do not live in water, but generally in moist situations. Many of them are very small, as the different kinds of mould which grow upon decaying animal or vegetable substances. Many of the larger fungi are pleasant and wholesome articles of food, as the common mushroom, the truffle, and the morel. Some of them, however, are very poisonous, and fatal accidents not unfrequently happen from the mistaking of one kind for another.

Another large order is that of *Lichens*, 'plants that lick up moisture' [Greek *leichēn*, from *leichō*, to lick]. Some of them form mere crusts upon the stone or bark on which they grow; some are expanded in a leaf-like manner; others form filaments and tufts. Lichens growing on rocks may be said to begin the process of forming a soil for other plants. *Iceland moss* is an example of a lichen used for food. Another kind, popularly known as *reindeer moss*, affords the chief winter-food of the reindeer in Lapland and other arctic countries.

Ascending in the scale of plant-life to the true acrogenous plants which have stems, roots, and leaves, the first order which demands special notice is that of *Mosses*, which chiefly abound in cold and moist regions. They are all small plants, but vast multitudes often grow together, covering the ground with a green carpet.

Another great order of acrogenous plants is that of *Ferns*. The largest ferns, those which become trees, are found only within or near the tropical regions. Few ferns are of much use to man, but their great beauty has led to their very general cultivation, not only in gardens and greenhouses, but in rooms of houses.

Endogenous Plants.—The two most important orders of Endogenous or Monocotyledonous plants are *Palms* and *Grasses*. Palms are only found in warm countries, and mostly within the tropics. The palm frequently mentioned in the Bible is the *date-palm*, which extends into more northern regions than almost any other species. Palms, in general, have tall stems, often shooting above the other trees of a tropical forest, and waving their great leaves in the air. Some of them, however, have very short stems, and some have very long slender stems, which clamber over trees, and depend upon them for support. Such are the *rattans* of the East Indies, the stems of some of which far exceed in length the most stately trees of the forest. Rattans are much used for making cane-bottomed chairs and for other kinds of wicker-work. The stems of some palms are used in house-building, and for other purposes; the great leaves are used for thatching,

[1] Plural of Latin *fungus*, a mushroom.

and often in Eastern countries as umbrellas; the fibres of various parts are used for cordage and clothing; the sap of some species is used as a beverage, and when fermented, resembles a kind of beer or wine—the *toddy* of India, from which, by distillation, a kind of spirit called *arrack* is obtained; the soft internal part of the stem of some species yields *sago*, and a few species are valuable for their fruit. The most important of these are the date-palm and the cocoa-nut palm. The date-palm supplies the inhabitants of Egypt and many other countries with a great part of their food. The cocoa-nut palm is found on the sea-coast of all tropical countries. The nut is valuable as an article of food and for the oil which it yields; and from the husk a kind of cordage is made, called *coir;* it is also much used for the manufacture of matting.

Grasses clothe a great part of the surface of the earth. To this order belong all the corn-plants, of which the most important are wheat, barley, oats, rye, rice, maize, and millet. Grasses are in general herbaceous plants with hollow jointed stems; but some tropical species, as bamboos, become shrubs or trees. Grasses afford the greater part of the food of oxen, sheep, and other herbivorous animals. The seeds of the corn-plants or *cereal*[1] grasses also supply a principal part of human food. The stems of bamboos are used for various purposes, as timber for the construction of houses, as pipes for conveying water, &c.

Only a few of the other orders of endogenous plants can be mentioned here. The order *Liliaceæ*, as its name implies, contains *lilies* and many other plants remarkable for the beauty of their flowers. To this order belong the medicinal plants called aloes and squills, also the flax-lily of New Zealand, from the leaves of which is obtained the valuable fibre called New Zealand flax.—The order *Amaryllidaceæ*, from Latin *amaryllis*, the snowdrop, contains a great number of species having very beautiful flowers, among which are the narcissus, jonquil, and snowdrop. Some useful plants belong to this order, as the onion and leek, and the American aloe, the leaves of which yield a fibre useful for cordage, and the juice of the flower-stem a beverage much used in Mexico, called *pulque.*—The order *Iridaceæ*, of which the *iris* and crocus are examples, is chiefly notable for the beauty of its flowers.—An important order of plants, all natives of warm parts of the world, bears the name of *Musaceæ*, from Latin *musa*, the plantain-tree. The plants of this order are among the largest of herbaceous plants, and false stems formed by the stalks of their great leaves give them the appearance of trees. The banana and plantain belong to this order. The plantain is used in many tropical countries as a substitute for bread; and of all the plants which supply human food, it is by far the most productive. The leaves of some of the *Musaceæ* yield a useful fibre, and that of one species, a native

[1] So called from *Ceres*, the Grecian and Roman goddess of corn.

of the Philippine Islands, has become a considerable article of commerce, under the name of *Manilla hemp*.—Orchids (*Orchidaceæ*) are a large order of endogenous plants, generally remarkable for the beauty as well as the curious structure of their flowers.

Exogenous Plants.—We now come to Exogenous plants, but of these the orders are so numerous that many which contain valuable species must be left unnoticed. A very important order, *Coniferæ* [Latin, 'cone-bearers'], contains pines, firs, larches, cedars, araucarias, junipers, &c. Among the *Coniferæ* are the tallest trees in the world, such as the great pines of California (*Wellingtonia gigantea*),[1] which attain a height of 300 feet or more, their stems rising erect almost to the very summit, and without a branch for almost half their height from the ground. Many of the *Coniferæ* are very valuable for their timber, which is remarkably resinous. From trees of this order we obtain also turpentine, tar, and pitch.

The *Amentaceæ*, from Latin *amentum*, a catkin, are so called from having their flowers in catkins, as willows, poplars, birch, alder, hazels, oaks, beeches, chestnuts, walnuts, &c. It will be seen, from the examples named, that among the *Amentaceæ* are many noble and beautiful trees, and some which are valuable for their fruits. They abound chiefly in the temperate parts of the world. Both the *Coniferæ* and *Amentaceæ* are destitute of corolla. The order *Urticaceæ*, from Latin *urtica*, a nettle, contains a great number of species, of which the nettle is an example. Many of the species have stinging hairs; and some Indian nettles sting with a severity far beyond that of the nettles of Britain. Yet the common large nettle of Britain, when gathered young and boiled, is perfectly wholesome, and nettle-broth was at one time in common use in Scotland. Hemp, which yields one of the most valuable of fibres, is nearly allied to the nettles, as is also the hop, of which the flowers are used for flavouring beer.

Closely allied to the *Urticaceæ* is the order *Moraceæ*, from Latin *morum*, the mulberry, to which the fig and the mulberry belong. The species are generally trees, and chiefly abound in warm countries, in which many species of fig are found, some of them rapidly covering ruined buildings with their branches and foliage. The banyan, already noticed, is a species of fig. The fruit of the common fig is very superior to that of any other of its genus. The sycamore, sometimes mentioned in the Bible, is another species of fig, the fruit of which is a common article of food in Egypt and Syria. Some species of this order yield abundantly caoutchouc or india-rubber.—To these orders, that called *Ulmaceæ*, from Latin *ulmus*, an elm, is also allied. It consists of trees and shrubs, of which the elms are examples. They have rough leaves, and are valuable as ornamental and timber trees.—The only other order which

[1] Named after the late Duke of Wellington.

it seems necessary to notice of the large group of exogenous plants destitute of corolla, is that called *Piperaceæ*, from Latin *piper*, pepper, to which the true pepper-shrubs belong, although Cayenne pepper and Jamaica pepper are the produce of plants of very different orders. They are generally small shrubs or herbaceous plants with jointed stems.

The orders of exogenous plants which remain to be noticed have generally both calyx and corolla. The order *Ranunculaceæ* consists chiefly of herbaceous plants, generally with a large number of stamens, most abundant in the colder parts of the world and in moist climates. To this order belong the *ranunculus*, anemone, and many other plants highly esteemed for the beauty of their flowers, and some which are of use in medicine, as aconite and hellebore.—The order *Nymphæaceæ*, from Latin *nymphæa*, the water-lily, consists of the plants commonly called *water-lilies;* their leaves are large, and float on the water. To this order belongs the *Victoria regia* (fig. 79, page 134), a South American plant, remarkable for the great size of its leaves and flowers, and for the cultivation of which special hot-houses have been erected in some gardens of Britain. The flowers of water-lilies are often both very beautiful and very fragrant, as in the case of the common white water-lily of Britain, and the blue water-lily or *lotus* of the Nile. They generally float on the water as the leaves do.—Another order closely related to these is *Papaveraceæ*, from Latin *papaver*, the poppy, to which poppies belong. Poppies are not only notable for their large showy flowers, but their seeds are edible, and yield a useful oil. The unripe capsules also contain the substance called *opium*, much used in medicine.

The order *Cruciferæ* [1] is a very large one, containing a great number of species, mostly herbaceous plants, natives of temperate and cold countries. To this order belong the kale—with the cabbage, cauliflower, broccoli, Brussels sprouts, and kohl rabi, which are mere varieties of the same species, variously modified by cultivation—the turnip, rape, radish, sea-kale, cress, water-cress, mustard, wall-flower, rocket, stock, honesty, and many other plants cultivated for various uses in fields and gardens, or esteemed for the beauty of their flowers. A peculiar pungent taste is very characteristic of this order; it is almost unperceived in the leaves of the cabbage or in the root of the turnip, but gives their most esteemed qualities to the root of the radish, the leaves of the cress, and the seed-leaves of mustard used as a salad, and is most perfectly developed in the seeds of mustard.—The order *Violaceæ* contains the beautiful plants called *violets*, some of which are much cultivated in flower-gardens under the name of *pansies*. Some plants of this order are valuable for their

[1] 'Cross-bearing,' from Latin *crux*, *crucis*, a cross, and *fero*, to bear, so called from their flowers, petals, or other parts being arranged in the form of a cross.

medicinal properties, particularly the ipecacuanha, which grows in the tropical parts of South America.

The order *Caryophyllaceæ*[1] is a large one, consisting of herbaceous plants with jointed stems swollen at the joints. Examples of it are found in the common chickweed, and in the pinks and carnations of our gardens.—In the order *Malvaceæ*, from Latin *malva*, the mallow, the leaves are in general palmate—that is, they are divided as a hand spread out into fingers—and all the soft parts are generally mucilaginous. The leaves of some are used for food. The mallow and hollyhock are examples of this order. The stems of some of the *Malvaceæ* yield useful fibres; but the most important species of the order are the cotton-plants, the valuable fibres of which are produced in their seed-vessels.—The order *Tiliaceæ*, from Latin *tilia*, the linden-tree, contains trees and shrubs resembling *Malvaceæ* in their fibrous and mucilaginous properties. To this order belongs the linden or lime tree, so common an ornament of pleasure-grounds. This tree abounds in some parts of Europe, particularly in the west of Russia, and *bast-mats* are made from its inner bark. An Indian plant of this order yields the fibre called *jute*, an important article of commerce, and used for manufacturing purposes like flax and hemp.

The order *Ternstrœmiaceæ* contains the tea-plants, shrubs which are natives of China, Japan, and Assam, and the leaves of which, dried in a peculiar manner, are *tea*. The flowers of this order are generally very beautiful, and the *camellias*, so much cultivated in our green-houses, belong to it.—Oranges, lemons, and citrons belong to the order *Aurantiaceæ*, from Latin *aurantium*, an orange, which consists of trees and shrubs, all natives of Asia, although some of them have long been cultivated in other parts of the world. The fruit of most species of this order is pleasant and refreshing; some kinds are very acid, but their juice is valuable in tropical countries as a preventive of fevers, or when diluted with water, as a beverage.—The order *Aceraceæ*, from Latin *acer*, the maple, contains the maples, trees of Europe and other temperate countries. The sycamore, a common tree in Britain, often called the *plane-tree*, although it is not the true plane-tree, but only somewhat like it, belongs to this order. The sap of maples abounds in sugar; and that of one species, called the sugar-maple, yields the *maple-sugar* of North America.—The order *Cedrelaceæ*, from Latin *cedrus*, the cedar, consists entirely of trees, natives of warm countries, of which the most important is the *mahogany-tree*, a native of the warmest parts of America, extremely valuable for its timber.—The order *Vitaceæ*, from Latin *vitis*, the vine, consists of climbing shrubs, one species of which, the grape-vine, is of great importance on account of its fruit, the *grape*, which,

[1] From Latin *caryophyllus*, the clove-tree.

when dried, is the *raisin*, and from the juice of which wine is made. Another well-known plant of this order is the *Virginian creeper*, often employed to ornament the walls of houses.—The order *Geraniaceæ* consists of shrubby and herbaceous plants, many of which have flowers of great beauty, esteemed ornaments of our gardens and greenhouses, as geraniums and pelargoniums.—Nearly allied to this is the order *Linaceæ*, from Latin *linum*, flax, to which flax belongs. The order is important chiefly on account of this species.

The order *Leguminosæ*, from Latin *legumen*, a pod, is one of the largest orders of *phanerogamous*[1] or flowering plants. Some of its species are trees of great size; some are very small herbaceous plants. The fruit is generally a pod, and the flowers are generally papilionaceous. Many useful plants belong to this order; some of them trees valuable for their timber, or as yielding dye-stuffs, of which logwood and Brazil-wood are examples; some for their foliage, as clover and lucerne; some for their seeds, which are used for food, as the pea, bean, lentil, kidney-bean, and chick-pea. One of the most important of dye-stuffs, indigo, is obtained from the leaves and stems of certain herbaceous species of this order, some of which are extensively cultivated in India.—Nearly allied to the *Leguminosæ*, notwithstanding great differences both in the flowers and in the fruit, is the order *Rosaceæ*. The *rose* gives its name to this order, and the flowers have generally an appearance somewhat resembling it. It contains trees, shrubs, and herbaceous plants, natives of tropical, temperate, and cold countries. Many of the most esteemed fruits belong to it, as the apple, pear, quince, medlar, loquat, plum, cherry, peach, nectarine, almond, raspberry, and strawberry. The fruit of some of these is a *drupe*, that of others a *pome;* whilst the rose, the raspberry, and strawberry afford examples of other kinds of fruit very different from these and from each other.—Another large order is that called *Myrtaceæ*, to which the *myrtle* [Latin *myrtus*] gives its name. It consists of trees and shrubs, mostly natives of the warmer parts of the world, and generally very beautiful. Some of them have eatable fruits, as the pomegranate and the guava; some yield fragrant substances. *Cloves* are the flower-buds of a species of this order; *pimento* or *Jamaica pepper* is the fruit of another.

Gourds, pumpkins, cucumbers, and melons belong to an order called *Cucurbitaceæ*, from Latin *cucurbita*, a gourd. It consists of climbing plants, mostly herbaceous, with large coarse leaves, natives of the warmer parts of the world. Acrid properties prevail in this order, and some of the species are poisonous. The medicine called *colocynth* is obtained from the fruit of one. The leaves of some, however, are used for the table as greens, and the fruit of a number of

[1] From Greek *phaneros*, apparent, and *gamos*, marriage—opposed to *cryptogamous*.

species is wholesome and pleasant. The melon, cucumber, water-melon, and vegetable marrow are particularly esteemed. Some kinds of gourd and pumpkin attain a very large size, and are an important article of food in many countries.—The *Cactaceæ*, from Latin *cactus*, the artichoke, are a large and remarkable order of succulent plants, all natives of America. Most of them have no leaves, the green surface of their stems and branches serving the purposes of leaves. Their stems assume many remarkable forms; they are often very spiny, and are employed in some countries for hedges. Some of them are very common in hot-houses in Britain, being cultivated not only on account of their curious appearance, but of the great beauty of their flowers. The fruits of some are eatable, particularly that of the prickly pear, which is now common in the south of Europe. It is on a plant of this order that the cochineal insect lives, and the plant is cultivated for the sake of the fine dye-stuff which the insect yields.—Allied to the order *Cactaceæ*, although very different in appearance, is the order *Grossulariaceæ*, from Latin *grossus*, an unripe fig, which consists of shrubs found in the temperate parts of the world. The gooseberry and currant are examples.

The order *Umbelliferæ* [Latin, 'umbel-bearers'] is a very large one, peculiar in its characters, and remarkable for its prevalent properties. It consists almost entirely of herbaceous plants, some of which are of very large size, and many of them of coarse appearance. The flowers are produced in *umbels*, and are generally very small, although the umbels are often large, and consist of a great number of flowers. The fruit is formed of two carpels, each producing one seed. The plants of this order very often have a strong smell, which in some is aromatic and agreeable, in others very disgusting. Many species are poisonous, of which hemlock may be mentioned as an example. Some of the poisonous species, however, yield useful medicines. The leaves and leaf-stalks of a few species are used as salads and pot-herbs, being valued chiefly on account of their flavour, as celery and parsley. The roots of some umbelliferous plants, as the carrot and parsnip, become large and fleshy in favourable circumstances, particularly under cultivation, and are valuable articles of food. The seeds of some, as caraway and coriander, are aromatic and agreeable.

A large order, containing trees, shrubs, and herbaceous plants, mostly natives of warm countries, is called *Cinchonaceæ*;[1] they have generally very beautiful foliage, and some of them have beautiful flowers. The coffee-tree belongs to this order; it is a native of Arabia, but is now extensively cultivated in many warm countries. The *coffee-bean* is its seed. Certain trees of this order, belonging to the genus *Cinchona*, yield the substance called *Peruvian bark*, from which *quinine*, one of the most

[1] From the *Cinchona*, so called after the Countess del Cinchon at Lima, who was cured by its use in 1638.

valuable of medicines, is extracted. These trees are all natives of the north-western parts of South America, growing on the slopes and in the valleys of the Andes.

A very large order of plants is called *Compositæ* [Latin, 'composite or compound'], because the flowers are grouped very closely together into heads, so that the whole head appears as one flower. This order contains many species prized for the beauty of their flowers, as daisies, chrysanthemums, marigolds, dahlias, and asters. The leaves of some are used as salads, as those of the lettuce and endive. The roots of others are eaten, as those of the salsafy and scorzonera; and the roots of the Jerusalem artichoke, which is a species of sunflower, produce tubers like the potato. The roots of chicory, dried and ground into powder, are used as a substitute for coffee, or for mixing with coffee. The receptacle of the head of flowers—the enlarged summit of the flower-stalk—is the eatable part of the artichoke; it is the same part which boys know as the *cheese* of thistles. Thistles belong to this order.

Heaths belong to the order *Ericaceæ*, from Latin *erica*, heath. The species of this order are very numerous. They are shrubs with evergreen hard leaves and extremely beautiful flowers. Many of them are what are called *social plants*, that is, multitudes of them grow together; and some of the species cover great tracts of country, as the common *heather* of British moors. To this order belong also *rhododendrons*,[1] or rose-trees, so called from the likeness of their flowers to the rose. —The olive gives its name to the order *Oleaceæ*, from Latin *olea*, an olive, to which the ash, the lilac, and the privet also belong. All the species of this order are trees and shrubs, natives of temperate countries.

The order *Solanaceæ*, from Latin *solanum*, the nightshade, is particularly important as containing the potato. No other plant of the order produces edible tubers; but the fruits of some are used, as those of the egg-plant and the tomato or love-apple. Poisonous qualities, however, generally prevail throughout the order. The species of *capsicum* are small shrubby plants of this order, remarkable for the pungency of their fruit, which far exceeds that of pepper. The berries of capsicums, often called chillies, are pickled to make *hot pickles*, and when dried and powdered, they become *Cayenne pepper*. Henbane belongs to this order, which also contains the *deadly nightshade*, the berries of which are very poisonous, and are sometimes unhappily eaten by children, who mistake them for blackberries. This order also produces tobacco, which is made of the leaves of several species of a genus called *Nicotiana*, from Nicot, who introduced tobacco into France in 1560.—The order *Scrophulariaceæ*, so called from the resemblance of their roots to scrofulous tumours, contains a great number of species,

[1] From Greek *rhodon*, a rose, and *dendron*, a tree.

mostly herbaceous, some of which are found in almost all parts of the world. Perhaps the most important of them is the foxglove or *digitalis*, which is used in medicine. Many of them have flowers of considerable beauty, as the calceolarias, veronicas or speedwells, and antirrhinums or snapdragons. The flowers of the *Scrophulariaceæ* have very often more or less that peculiar form which is seen in the calceolarias and antirrhinums.

Another large order is that of *Labiatæ*, from Latin *labium*, a lip, in which also the corolla generally divides into two parts or *lips*. The plants of this order are mostly herbaceous plants or small shrubs, and many of them are remarkable for their fragrance, which is due to an essential oil abounding in their leaves. Some of them are used in cookery for flavouring, some in perfumery, and some in medicine. As examples of this order, it is enough to name mint, thyme, lavender, patchouli, sage, hyssop, rosemary, marjoram, basil, and savory.—The order *Verbenaceæ* contains the beautiful flowers cultivated in our gardens under the name of *verbena* [Latin *vervain*], and the shrub common not only in greenhouses but in cottage windows, which generally receives the same name, remarkable for its orange-like fragrance. It contains also the teak-tree of India, one of the most valuable of timber-trees.—The last order which we shall notice is *Primulaceæ*,[1] an order consisting of herbaceous plants, none of which are of large size, but which generally have very beautiful flowers. They are mostly natives of temperate parts of the northern hemisphere. The primrose, the cowslip, the auricula, and the pimpernel are examples of this order.

1 From *primula*, the primrose, from Latin *primulus*, very early, so called from its flowering in the beginning of spring.

Fig. 79.—Victoria regia, flower and leaf.

GEOLOGY.

Nature of the Subject.

We have most of us stood at the base of a great cliff, and looked upwards with awe at the rocks exposed on its weathered front. Such a sight might suggest many strange and interesting inquiries. How did these rocks come to be where they are? Of what are they composed? When were they formed? Whence the material for the vast thickness of rock that composes the crust of the earth? Whence have come the varied substances that form our limestones, coals, and sandstones? Whence also the strange shells, plants, and animals that a closer examination of their structure reveals? Are these the remains of bygone living organisms, or are they only marks in the rocks themselves? If they were once living creatures, what were their structure and habits? Such questions suggest themselves to every thinking person, whether man or boy, and such questions Geology undertakes to answer; and it is to the principles of this great science that we now proceed to direct attention.

Geology, from the Greek *ge*, the earth, and *logos*, a description, is, according to its name, a description of the earth. It examines the various rocks that compose its crust, and seeks to explain their appearance, form, structure, relative position, formation, age, and distribution throughout the globe. It also inquires minutely into their contents, animal, vegetable, and physical; the causes of their imprisonment in their stony tombs; and the structure and habits of the creatures there found. It pictures forth the physical history of the globe during the successive epochs through which it has passed, with their varied scenery and inhabitants, the formation of its many strata, and the structure and progress of the organic forms that successively waved in its atmosphere, moved over its surface, or swam in its seas. In short, it is the province of Geology to describe the whole natural history of the globe during the various ages of the long past; and it includes the zoology,

botany, mineralogy, and geography of the ancient earth, whose present conditions are the result of the numberless changes through which it has passed in these geological eras. The past it seeks to interpret solely by the present, assured that the laws of nature are invariable and universal, and that causes operating now produced like effects in the primeval earth.

Rocks, their Kinds, Structure, and Disposition.

In order to speak with precision in our study of this subject, it is necessary to have a distinct idea of what a rock is in Geology, and to understand certain things regarding their kinds, structure, and arrangement.

What a Rock is in Geology.—In Geology, the word Rock has a wider meaning than it has in common language, where it means a mass of stone of considerable size. In this science, the word Rock is used to designate *any of the materials that compose the crust of the earth*, of whatever size and softness they may be. Geologists reckon sandstone, marble, quartz, granite, and limestone to be *rocks*, as others do; but they also speak of coal, gravel, chalk, sand, salt, peat, and like soft and broken substances, as *rocks* or rock-formations.

Kinds of Rocks.—Rocks have different names, according to their appearance and structure. Every one knows what *sand* is, and that it varies greatly in fineness. The most of the sand we see is composed of small particles of rock ground to powder, but it often consists, as we shall afterwards learn, of numberless very minute shells. *Sandstone* is the usual rock of which houses are built, and which, in thin layers, is used for pavement. This rock is more common than any other, and has many varieties, and is, of course, so called because it is composed of particles of *sand* that have been made to cohere. When the particles of the sandstone are somewhat larger and sharper, the rock is called *grit*, from the particles having been *grated* down or broken: the rock of which millstones are formed is called millstone-grit, and its value depends on the hardness and sharpness of the grains of which it is composed. When the particles are larger still, and form small stones that do not cohere, the rock is called *gravel;* and when yet larger and more rounded, *shingle*, examples of both of which occur on the sea-beach. A mass of broken angular stones thrown up in a heap, as by a river after a flood, is called *rubble*. A stone when small is called a *pebble;* when large, a *block;* and when rounded and worn, a *boulder*, because it is *ball*-shaped. The fine sediment at the bottoms of rivers, lakes, and pools is composed of ground mineral, animal, and vegetable matter. When this is tough and plastic, it is called *clay*,

because it *cleaves* or sticks; and the whole accumulation of mud, clay, and sand at the bottom of any water, is called *silt*.

The remains of vegetable matter found in various parts of the country, and used as fuel, are known as *peat;* and *coal* is nothing but such vegetable matter changed by heat, and hardened into rock by pressure. *Limestone* is the name given to the hard rock which, after being burned in a kiln, forms *lime*. When the limestone is hard and crystalline, it forms *marble*, which is of different colours, from deep black to pure white, and often beautifully variegated. *Chalk* is a variety of limestone, and obtains its name from this fact; the word chalk being another form of the Latin *calx*, lime.

Common *slate*, used for writing on and for roofing, is composed of thin layers of hard rock, of which some of our highest mountains are formed. The name *shale* is applied to a kind of rock which *shells* off or splits into very thin layers, and which may be seen in great heaps near coal-pits. Thin layers of sandstone used for pavement are called *flags*. The white pebbles so common on the sea-beach, and so easily broken, are made of *quartz*, and rock formed of it is called *quartz-rock*. Some varieties of quartz, called *rock-crystals*, are very beautiful and valuable, and become even precious stones, such as agate, amethyst, and topaz. *Flint* has much the same composition as quartz, and is very plentiful in chalk. The granular rock brought from Aberdeen and elsewhere, so beautiful when polished, is called *granite*, from its being composed of *grains* of other rocks. The particles that glitter like silver in the granite are pieces of *mica*,[1] which is so named because it *shines*. A mineral very like mica in appearance, but different in composition, is called *talc*, from its feeling somewhat greasy or *tallowy* when touched.

The molten matter that *flows* from volcanoes is called *lava;*[2] *pumice-stone*[3] is the *cinder* of such discharges; while the *ashes* that are thrown into the air are called *scoriæ*. In geologic times also there existed volcanoes from which lava issued; the rock this lava formed is called *trap*,[4] from lying in *stair*-like masses, as it flowed from the mountain; and one kind, *whinstone*, which is much used for roads. A common variety is known as *greenstone*, from its colour, of which Salisbury Crags, near Edinburgh, are composed. Another variety is called *basalt*, and is generally found in columns standing close together, which often form wonderful natural scenes, such as Fingal's Cave and the Giant's Causeway. Another variety is *porphyry*,[5] so called from its frequent *purple* colour, and is easily distinguished by its granular appearance. A kind of light porous rock, formed of cohering volcanic

1 From Latin *mico*, to shine.
2 From Latin *lavo*, to flow.
3 From Latin *pumex*, *-icis*, cinder.
4 From Latin *trappa*, a stair.
5 From Latin *porphyra*, purple.

ashes, is known as *trap-tuff*, or *tufa*, a word that comes from Italy, the seat of so much volcanic action.

Structure of Rocks.—On examining the rocks forming the crust of the earth, we find that they may be divided into two great classes—the *stratified*, or those deposited in strata or layers; and the *unstratified*, or those not so formed. Sandstone and slate are stratified rocks; granite and trap are unstratified.

1. *Stratified Rocks.*—Any thin deposit of rock is called a *layer*, from its having been *laid down* under water; a *band*, from its being like a thin band; a *bed* or a *stratum*, when of greater thickness, from Latin *sterno*, to spread; and a *seam*, when of a peculiar character as compared with the rocks near it, as a seam of coal. *Stratum*, with the plural *strata*, is the general term for any layer of rock, and hence all rocks in layers are said to be *stratified*. Rocks that split up into very thin layers, a great number being included in the thickness of an inch, are said to be *laminated*. When a rock is composed of rounded pebbles or boulders embedded in other matter, it is called a *conglomerate*, and sometimes, from its appearance, *pudding-stone* or *plum-pudding-stone*.

2. *Unstratified Rocks.*—Unstratified rocks assume various forms, according as they have been shot up amongst the stratified rocks; for, as we shall afterwards see, they have been erupted from volcanoes. Very often, like most volcanic substances, they are *porous* or *cellular*, like pumice-stone; frequently they stand together like gigantic columns, when they are said to be *columnar*, like basalt; and often they are found in large *globular* or *spherical* masses, like bombs or cannon-balls.

Disposition of Rocks.—1. *Stratified Rocks.*—When rocks lie parallel to the horizon, they are termed *flat* or *horizontal*, as A, in the following section; when at an angle to it, they are said to be *inclined* or *dipping*, as B; when one end has been thrown up by some other mass, they are said to be *tilted up*, as R; when so much inclined as to be straight up and down, they are said to be *perpendicular*, or *to stand on edge*. When inclined rocks come to the surface, they are said to *crop out*, and the exposed edge is therefore termed the *outcrop*, as M; the angle at which they are inclined is called the *dip* of the rocks, and is measured by the number of degrees from the horizontal in any direction, as 60° S.; and the line of the outcrop along the surface is termed the *strike* or *line of strike*, because it strikes or runs across the country. When the strata are not straight, they are said to be *bent* or *curved;* and when greatly bent, *twisted* or *contorted*, as P. When all the strata in a series lie at the same angle, they are called *conformable;* when at different angles, *unconformable*, as at A. Sometimes certain strata seem to have slipped or to have moved up, so that rocks that should be opposite to one another are not so. The portion that has slipped is naturally termed a *slip*, as C;

that which has been heaved up, an *upheaval* or *hitch:* where the strata at the slip lie at different angles, the slip is called a *fault*, as O. All such displacements of strata are known as *dislocations*, and they are much more frequent than the regular disposition of rocks on the surface of the earth. When strata are bent in wavelike undulations, they are said to *roll*, as H ; and the hollow or concave portions are termed *troughs* or *basins*, and the elevated portions *ridges*, as I and K.

2. *Unstratified Rocks.* — These rocks are thrown up amidst the stratified, and assume different positions according to the manner of their upheaval. Where they throw the strata into various angles, the rock upheaved is termed the *disrupting* mass, as V ; at other times, they overlie the other rocks, and are then called *overlying*, as E ; they are also interjected *between* the other *strata*, and are said to be *interstratified*, as F. Sometimes they intersect the other strata by masses like walls, which are called *dikes*, as G ; and sometimes the disrupting mass breaks into branches, which are called *veins*, as N.

When a broad face of rock is exposed, and the different rocks shewn, as in a cliff on the sea-shore, a railway-cutting, or a quarry, such exhibitions of strata are called *sections;* and these may be delineated on paper. Sections of the underlying rocks may also be made, by examining the different rocks in a country, though no section be exposed in nature.

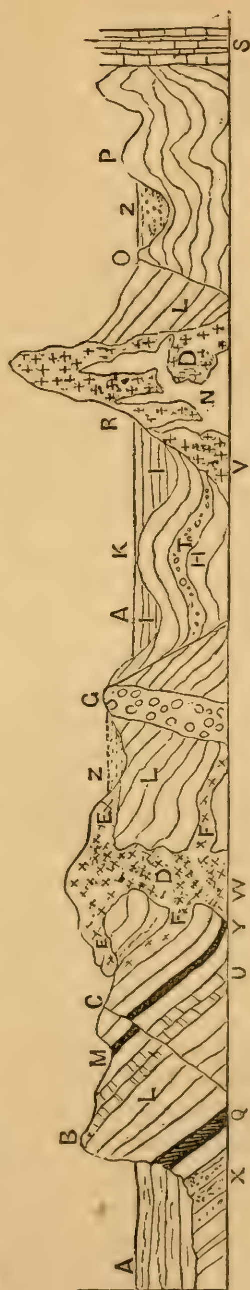


Fig. 80.—Section of the Different Kinds of Strata.

A, Horizontal and unconformable rocks.
B, Inclined strata.
C, A slip.
D, A disrupting mass.
E, Overlying trap.
F, Interstratified trap.
G, A dike.
H, Bent and rolling strata.
I, A basin or trough.
K, A ridge of rocks.
L, The dip of the rocks, 45°.
M, An outcrop.
N, Veins.
O, A fault.
P, Contorted or twisted strata.
Q, A seam.
R, Rocks tilted up.
S, Columnar basalt.
T, Conglomerate.
U, Limestones.
V, Granite, disrupting.
W, Trap.
X, Sandstones.
Y, Coal.
Z, Silt or gravel.

The Contents of the Rocks.

The contents of the rocks receive the general name of *fossils*, from the Latin *fossus*, dug, because they require generally to be *dug* out of the earth. Fossils may be divided into two great classes, animals and plants.

Fossil Animals.—In the rocks, we discover specimens of every class included in the animal kingdom. We find corals of all kinds, and of the most beautiful structure, some branched like some of the corals of the present seas, others standing in masses on the very spots where they lived and died, their remains giving beauty to our finest marbles. We see star-like creatures of all kinds, either spreading abroad their arms or curled up at rest, as they may be seen any day during the ebb of tide. Shells of every form, size, and colour meet us at every step, as distinct as we now find them on the shore; and some formations, of vast thickness and extent, are formed entirely of the habitations of these little creatures. We may also gather crustaceans, such as the crab and the lobster, the minutest parts of their structure being perfectly preserved. We discover fishes of every kind and size, sometimes entire, as they fell to the bottom at death, or crushed and broken in the convulsions to which the rocks have been subjected. We can gather the hard scales, that defended them like armour; can form collections of their teeth, their fins, their jaws, and their eggs; and can construct them again as they swam about in the ancient seas. Insects, too, we can gather of every kind, and can see them as they flew about in the old forests and got entangled in the resin of the great old trees. Birds, too, are found, though not so plentifully as other creatures, as, from their manner of life, they were not so easily carried down by rivers, and deposited in the mud at their mouths. We find reptiles of immense size, crocodiles, and lizards, and flying dragons, with their terrible teeth, sweeping tails, and adamantine hides. We come upon beasts of every size, from little creatures that burrow in the ground, to gigantic deer, elephants, rhinoceroses, and mammoths; and may enter the very dens in which lived beasts of prey, and to which they bore their captured victims.

These creatures differ more or less from those that now inhabit the globe, but they are members of the same classes; and catalogues of them have been formed as of those of the present day. A visit to a museum in which fossils are exhibited would astonish you with the multitude, variety, and beauty of those fossil creatures, and especially with the wonderful preservation of organisms the most delicate and frail.

Fossil Plants.—But the vegetable kingdom is as fully represented in the rocks as the animal. We find trees of the most varied kinds, with their roots, stems, branches, leaves, flowers, and fruit. We can look

with wonder on the exquisite carving on the stems of mighty trunks, hundreds of feet in height, that once formed forests as dense and impenetrable as those of the Amazon. But more, we can behold the trees standing on the very places in which they grew and waved their great branches, and can trace their roots as they penetrate the soil beneath. We can also gather plants of all kinds—reeds, mosses, rushes, seaweeds, and beautiful ferns—preserved entire, and spread out on the rock as delicate and perfect as in the finest herbarium. These fossil plants have, like the fossil animals, been examined and classified by botanists, and we possess elaborate volumes on the botany of the remote ages when these plants grew, similar to those on the existing flora of our globe.

Traces of Natural Operations.—But the rocks bear traces of more than all this. On them, we can see the very dints of the raindrops of these bygone ages, and can calculate the direction and force of the showers that impressed them. We can walk over the rippled sands of the old seas, just as we can do over those we played on in childhood. We can also look on the footprints of primeval birds, as they stalked in the mud of their lake or river homes ; or gaze with astonishment on the great footprints, as large as a man's hand, of the huge reptiles that waddled among the reeds by the great old rivers. We can look into the craters of extinct volcanoes, can follow the flow of the destructive lava, and can gather the ashes that once illuminated the darkened heavens. We can trace the sources of ancient rivers, and dig in the mud brought down from their mountain sources ; can draw maps of the continents and seas as they existed thousands of ages past ; can tell where great ocean-currents flowed, bearing huge icebergs, that grated the sea-bottom, and left their indelible traces on the granite and trap of our present hills ; and can shew where mighty glaciers once existed in valleys famed for their beauty, where now the genial sun sheds its warmest rays. In short, every element in nature, whether of air, river, or ocean, has left its deepest traces on the solid crust of our wonderful globe.

Agencies in the Formation of Rocks.

We now proceed to inquire into the manner in which rocks have been formed. Any explanation must account for *all* the phenomena, equally of composition, structure, arrangement, and contents. We must, for instance, explain how some rocks are stratified, and others not ; how some are horizontal, and others inclined ; and how plants and animals have come to be embedded in them so far below the surface. Are there, therefore, any agencies engaged in the formation of rocks at the present time that produce effects the same in kind with these older masses ? If we find

that such exist, we shall have a key by which to interpret the rock-formations of the past. Let us consider, therefore, the Rock-forming Agents.

Volcanic Agents.—The most obvious rock-formers at present in action are volcanoes. From circular openings, called *craters*[1] from their *cup-like* shape, at the summits of these mountains, there issue forth at certain times great streams of molten lava, boiling water, red-hot fragments of rock, mingled with flames, and smoke, and steam, amidst confused and thundering sounds, and the general convulsion of the surrounding country. These lava-streams, increased by ashes and other substances, are often of great thickness, sufficient to bury cities ; as Vesuvius once did Herculaneum and Pompeii, and Etna did Catania at its base, where the river of lava gradually rose round the walls, finally drowning the city in its burning flood, after it had flowed twenty-four miles ! Successive accumulations of such outbursts deposit immense masses of rock, in the course of ages, round the centre of eruption ; so great, indeed, that the larger portion of such mountains—and some of those in America are five miles in height—are formed of the successive accumulations of the crater itself. The molten lava assumes various appearances after it has lost its heat : under water, it remains hard and compact ; in the open air, it becomes porous and cindery ; and in certain cases, it assumes a columnar form. All around, lie light pumice-stone, slag-like masses, fine pulverised dust, and huge calcined blocks. Now, the Unstratified rocks resemble in every feature these volcanic discharges. We meet with the compact lava in our trap and greenstone ; with the cinder, in the lighter porous rocks ; with the ash, in our trap-tuffs ; and with the columnar, in the basalt. In exposed sections, we see the very channel through which these masses burst and overflowed the strata above ; and can trace the boundaries of the ancient molten streams in the cliffs and hills that everywhere vary the surface of the country. We can also see hardening and crystallising changes produced on the surrounding strata, wherever the heat of the erupted matter penetrated. We have therefore found the explanation of one great class of the rock-formations, the Unstratified, in the volcanoes scattered over the globe, that are at this moment depositing masses identical in kind with those that issued from the bowels of the earth in bygone ages. Such rocks, therefore, are termed *igneous*,[2] from being produced by *fire ; volcanic*, from having issued from *volcanoes ;* and *eruptive*, from being produced by *eruptions*.

Aqueous Agents.—Rivers, as they flow over their channels, gather accumulations of mud, sand, gravel, and animal and vegetable remains, according to the size of the stream and the character of the country through which they pass ; and these they deposit at their mouths in seas or lakes. Sometimes the amount of débris thus deposited is

[1] Greek, 'a cup.'   [2] From Latin *ignis*, fire.

so great as to form large tracts of land, as at the protruding mouths of the Ganges, Nile, or Mississippi. Even in historic times, the land thus gained is of great extent. For example, at the mouth of the Po, a minor stream, the town Adria, which gave its name to the Adriatic Gulf from its extensive commerce in Roman times, is now nine miles from the sea! The mass of matter held in solution or borne along by the running water, sinks to the bottom when it reaches the sea, in a certain order. First the heavier masses are deposited, such as boulders and gravel; then, the sand; and last, the mud. Mingled with these are various animal and vegetable remains that have been washed into the stream. Thus, every river-mouth presents an ever-growing series of beds of varying thickness and material, superposed the one on the other, and enclosing various remains of animal and vegetable life. These strata would, in the above order, be converted, by pressure, into conglomerate, sandstone, slate, shale, and coal. Thus, again, we have found a beautiful and perfect explanation of the Stratified rocks as they are presented everywhere, by which their composition, stratification, and contents are fully accounted for. Stratified rocks, therefore, obtain the various names of *sedimentary*, because formed of the *sediment* of rivers; and *aqueous*,[1] because deposited under *water*.

Organic Agents.—But animal and vegetable life is also busy in the formation of rocks. Away in the warmer seas of the Pacific, lives the coral insect or zoophyte, the skeletons of which compose the remarkable coral reefs that form the chief part of the numerous isles that stud that greatest of seas. These reefs extend thousands of miles, in broad barriers, over which the wild waves dash, or in detached groups that gradually gather round them material and form new islands. In the rocks, we also find the remains of like corals, standing where they grew, or drifted away, and appearing as extensive formations of limestone.

Again, the bottom of the sea is covered with accumulations of minute shell-fish, of great depth and over extensive areas, as is proved every day by soundings with the lead. Now, the old rocks exhibit strata of identical composition with these microscopic shells; some limestones and chalks, for example, being composed of millions to the square inch of perfect bivalve shells. Again, the sea-bottom contains beds of shell-fish, of different kinds, and of great extent and thickness. Should these die, and then be subjected to sufficient pressure, they would form a rock, exactly like the shell limestones so common in our rock-formations, and so valuable in agriculture and building.

Then we have the remains of ancient forests in our great mosses; and luxuriant growths of swampy plants and impenetrable jungle in the mud islands of the deltas of our great rivers in the tropics. These,

[1] From Latin *aqua*, water.

submerged and acted on by heat and pressure for ages, would become coal, in every particular the same as that we daily use for fuel.

Thus, organic life of all kinds is everywhere busy in forming rock-masses, identical in character and appearance with those presented to our investigation in limestone, chalk, and coal.

Agencies in the Alteration of Rocks.

Rocks are changed from their original position, form, and structure by two classes of agents—those that disturb, and those that wear or disintegrate.

Disturbing Agents.—Stratified rocks in their natural state would be horizontal, or only slightly inclined. How, then, are we to account for the tiltings, upheavals, faults, and various dislocations so prevalent among the strata? The igneous forces, just spoken of, furnish the solution. The whole globe is subject to convulsive movements from the motion of the interior molten matter of the earth, which are seen in earthquakes, and by which the ground is torn into fissures, and the solid crust made to move in mighty undulations, that destroy and swallow great cities. Extensive tracts are also sometimes suddenly raised or depressed. Sometimes, too, great yawning craters open where previously volcanic movement was unknown, and continue for a time in active eruption. In these upheavals and subsidences, sudden or gradual, of extensive tracts, we see the causes at work of the dislocations of the rocks of former times, and of the elevations and depressions that occurred throughout the geologic eras.

Again, we know that in order to the deposition of strata of any thickness, the sea-bottom must have gradually subsided: does any such gradual subsidence take place at the present time? It is ascertained, from extended observations, that on the northern shores of the Baltic, for instance, there has been a gradual rise at the rate of 4 feet in a century, and in South America a rise of 85 feet during the human period, and at Valparaiso of 19 feet in 220 years; while over all the world, and even round our own coasts, ancient sea-beaches may be seen at various elevations, marking former sea-levels. On the other hand, the south coast of Sweden, the coast of Greenland over 600 miles, and parts of South America for the last 300 years, have been slowly sinking; nor are the British shores free from such oscillations.

Thus, again, we see that existing causes perfectly explain the *gradual* subsidences necessary to the formation of the rocks, and to their subsequent elevation into dry land.

Disintegrating Agents.—Every stratified rock in the immense thick-

ness of the crust of the globe has been formed of the débris of pre-existing formations, that have been ground down and held in solution till deposited in the layers afterwards hardened into rock. Whence, then, this immense accumulation of matter, and what the disintegrating agents ?

1. *Atmospheric Agency.*—The atmosphere, by its chemical action, and by the combined effects of alternate heat and cold, wetness and dryness, is continually crumbling down all exposed surfaces, forming new soil, and thus increasing the earthy covering of the globe. The wind, also, has an incredible power of drifting and heaping up sandhills along the shore—as in the county of Elgin, where an ancient barony has been entirely reduced to a desert through this means—and in raising the waves of the sea, and wearing the rocks through the mighty force of its swooping billows. Frost, too, is one of the quietest but most powerful disintegrating agents ; for when water has percolated a mass of rock, the act of freezing exerts a great expansive force which cracks the rock. But frost can work on a grander scale, for to its agency is due the existence of avalanches, glaciers, and icebergs; which, whether sweeping with overwhelming convulsion, or crawling down the mountain side, or floating and grating on the ocean floor, continually and with terrible effect, wear down or dash to pieces every rock that obstructs their irresistible course.

2. *Aqueous Agency.*—The most extensive aqueous agent is rain, which wears, softens, percolates, and gradually wastes away every rock on which it falls. The rain-water also gathers under the ground in large cavities, where springs are formed, which dissolve the interior rocks, and, bursting out, deposit their solutions of lime, iron, sulphur, soda, flint, and bitumen. One of the most powerful degrading agents is, of course, the sea; which, as it beats on its rocky shores, wears, rolls, and grinds to powdery sand the flintiest rocks, and presents as monuments of its mighty power of waste those lofty cliffs that guard its shores. But more powerful, but less obvious agents of destruction than the sea, are the many streams that everywhere traverse the land on their way to this boundless reservoir. The power of rivers in excavating and wearing away the surface of the globe is much greater than at first thought might be supposed. Every valley, however deep, has been mainly worn down by river-action, extending over immense periods of time. When we contemplate the mighty valleys enclosed by towering peaks capped with eternal snows, that lie hid amidst the mountain solitudes of the Alps, the Andes, or the Himalayas, we may well be astonished at such a statement. But that these huge excavations have been mainly produced by the combined action of air, frost, rain, and river, has been demonstrated beyond a doubt by a vast accumulation of facts and reasonings on phenomena in all parts

of the globe. Hence, valleys thus excavated are termed *valleys of erosion*,[1] from being ground out by the powerful action of these mighty agents. This being proved to be the case even during the human period, we are at no loss to account for the great denudation everywhere seen; and for the immense accumulations of sedimentary matter that form so much of the solid crust of our globe.

Transporting Agents.—We have finally to account for the deposition of strata in one part of the country, the materials for which have been obtained at great distances; and for the transport of immense boulders hundreds of miles from their original seats, as exhibited in all parts of the globe.

1. *Aqueous Agency.*—The most obvious agents of transport are rivers, that bear down from every part of their courses the débris deposited at their mouths. Their power of carrying masses of the heaviest materials is immense, as may be seen after a flood in the smallest streams in our neighbourhood. Waves have also a wonderful power of removing and carrying to a distance the blocks on which they daily dash. But the currents that flow through the ocean, which are but mighty ocean rivers, have the greatest influence in this respect. By their means, materials of all kinds, organic and inorganic, are conveyed to incredible distances. The Gulf-stream, for instance, conveys substances from the South African coasts to those of Norway and the far North.

2. *Ice Agency.*—But the transporting influence of these currents in bearing rock-masses is greatest when icebergs are carried on their surface. These huge frost-mountains have embedded in their mass the largest blocks, which are gradually dropped over wide areas as the ice slowly melts away. The size and number of some of these transported rocks are often almost incredible. Every country exhibits such travelled rocks, which are called *erratic boulders;* and our own little island presents no mean examples of such ice-borne masses.

But ice also acts as a transporter in the form of glaciers—those great ice-rivers that fill the upland valleys of the Alps, Himalayas, and such mountain systems. In front of every glacier, along its sides, and on its surface, are great collections of rocky fragments of every size, borne down by the ice-stream, and left as evidences of its existence when the glacier has melted away. Such collections of rocks are called *moraines*, from their *mural* or wall-like aspect as seen running across a valley. The distance to which such blocks are borne is astonishing, and depends on the size of the glacier. Evidences of extinct glaciers are seen in most countries, and we may trace their remains in our own island, where now not a particle of glacier ice can exist.

[1] From Latin *e*, out, away, and *rodo*, *rosum*, to gnaw.

3. *Igneous Agency.*—It is evident that volcanoes have a great power in throwing out masses of different materials to great distances, and of carrying many substances on their mighty lava-streams; and evidences of their power in this respect in geologic times are everywhere apparent. Sometimes the fine ashes that issue from the crater are borne by the wind to great distances, often fifty or a hundred miles, where they are deposited as a layer of finest dust; and this may account for the existence of trap-tuffs in places where no volcanic eruption seems to have taken place.

It thus appears that the agencies now at work on our own globe are adequately sufficient to account for all the phenomena of the forming, disturbing, disintegrating, elevating, depressing, and transporting of the rock-masses that form the crust of the earth. Such being abundantly proved, and the laws of nature being uniform and unchangeable, we are not only warranted, but compelled, to infer that the same influences were at work in these bygone ages, and were the joint causes of the formation of our rock-systems as they are now presented to our eyes and subjected to our investigation.

Examples of Geological Reasoning.

We shall now give some examples of the method of reasoning on the various phenomena presented in the rocks, the formation and history of which it is the province of Geology to unfold.

Reasoning regarding Rock Sections.

1. *Section with Igneous Action and Dislocation.*—From the section (fig. 81) let us see what we can discover, by the mutual relations of the rocks,

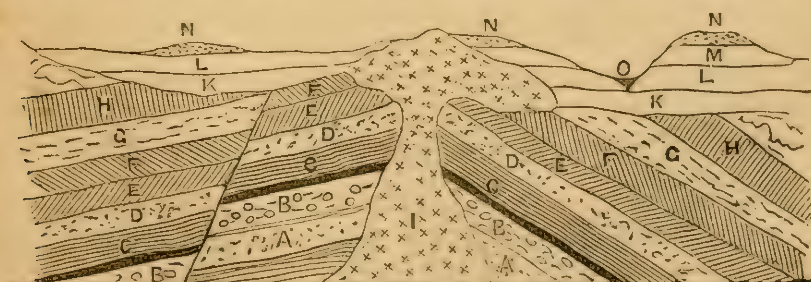


Fig. 81.

regarding the times of their formation and dislocation. Which rock was first deposited in this section? The lower rocks were of course formed

first, and the various strata were formed in the order of their superposition. You will observe that the strata marked from A to H are inclined, and, as these must have been deposited horizontally, they must therefore have been tilted up afterwards. We also see that the cause of their disturbance is the upheaval of the igneous mass I, which, issuing from beneath, has ruptured the strata previously flat, and overflowed part of the rocks where it rose to the surface. This upheaval has also thrown the strata at different angles, those to the right being more inclined than those to the left, and therefore forming a *fault.* We observe also that in the rocks to the left there occurs a great *slip,* for part stands at a different height from the rest. We can, however, easily trace each rock, as, for instance, the coal-seam C, from the one side of the section to the other through both slip and fault.

We also observe that after the trap eruption, the exposed rocks were subjected to long-continued water-action; for their outcrop is hollowed out into two valleys. After this period of denudation, the horizontal strata were deposited, and have not since been disturbed by volcanic action. We see also that a great part of the trap is covered by this new deposit, so that what was once a hill, before this new rock was laid down, is now almost hidden beneath the surface. The horizontal undisturbed rocks have, however, been much worn away by water-action; for deep valleys have been excavated in them, and the bed of a river still continuing the scooping out is seen at O. By looking at the highest and therefore last-formed deposit, we observe that it consists of gravel or silt. This, therefore, once formed the bottom of a lake or inland sea, where river-débris was deposited. This débris has been allowed to lie undisturbed till elevated above the sea-level, after which it has been worn down by streams. Patches of it still remain on the hill-tops over various parts of the surface, as at the points marked N.

2. *Section with Aqueous Action alone, without Dislocation.*—This second section (fig. 82) is of a part of the north coast of Norfolk, near the town of Cromer, and it is very striking and instructive. Let us see what we can learn from it regarding the history of the Norfolk shores. This section differs from the first in the entire absence of igneous action, for there is no displacement of any kind, its regularity being due to aqueous causes alone.

The lowest rock (A) is chalk, in which we can see represented regular rows of flints. This chalk consists of the remains of shell-fish and other creatures, whose organisms are found in the flints. After the deposition of the chalk, the land was raised, and a great forest grew over the chalky soil, which is well suited for the growth of trees. The roots of the old oaks, with part of their stems, are still seen erect as they grew!—embedded in the mud that accumulated round them when afterwards submerged.

But more remarkable still, at the time when these trees grew, huge elephants, rhinoceroses, and deer roamed over England, and strayed in the woods; as we know from their remains being found in this layer in many parts of the country! The forest afterwards sank under the waters of a

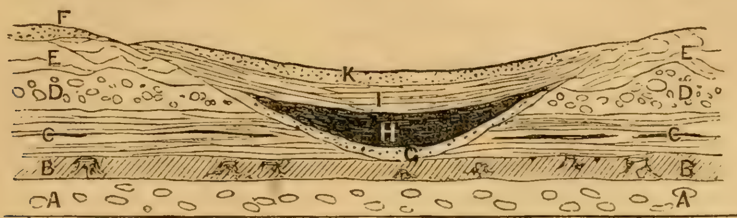


Fig. 82.

A, Chalk.
B, Forest bed, with elephant, rhinoceros, stag, &c., and tree roots and stumps.
C, Finely laminated clay, with shells.
D, Clay, with boulders, worn and scratched.
E, Contorted clay and gravel.
F, Gravel.
G, Coarse river-gravel.
H, Black peaty deposit, with shells, seeds, scales, and bones of pike, perch, and salmon.
I, Yellow sands.
K, Drifted gravel.

lake, and remained submerged for a long time, during which the thick deposit of clay was laid down, containing remains that lived in its waters. After the clay, a new agent acted upon the country. As will afterwards be shewn, the British Isles were subjected to the action of ice, the high mountains being covered with great glaciers, while icebergs floated over the submerged land, carrying boulders, and grinding down the surface of the land over which they passed. Here, away in Norfolk, we have the débris of what perhaps had been grated and rolled from the peaks of Wales and Cumberland! Then followed the deposition of the sand and gravel marked E and F. We observe, however, that F, though appearing on the left, has been washed away from the right side of the valley. After this gravel was laid down, a great river rolled its waters across the country, and wore away the strata, till it formed the deep valley that occupies the centre of the section. The gravel of this great river is still seen at the bottom of the hollow at G. Then followed a period when this valley formed the bed of an immense lake, into which flowed streams bearing the vegetable remains that now form the peat H. In this peat we find the scales and bones of the fish that gambolled in its waters—the perch, the salmon, and that fierce water-wolf, the pike. After this lake dried up, the sea flowed in, and the old river-valley became a bay or gulf, with its yellow sand I, and gravel K. These have subsequently been scooped out by streams, as shewn by the bend in the surface. We have, at last, reached the present time, when Norfolk was raised above the ocean, whose ancient bed is now trodden by the farmers and children of that fertile county.

Such are examples of the old-world stories disclosed by every rocky shore, railway-cutting, and river-cliff. We have been describing not what might have been, but what *was;* for we can prove every assertion, seeing that the rocks themselves furnish incontrovertible data.

Reasoning regarding Surface Phenomena.

1. *Iceberg Action.*—In some parts of Britain, as in the central region of Scotland, there are exhibited certain remarkable appearances from which striking deductions may be drawn. We find that all the hills, eminences, and rocks are precipitous towards the west, and exhibit traces of being rendered so by a mighty force wearing them down on that side. In the level ground between these heights we find a thick deposit of fine blue tenacious clay, with embedded stones, rounded and water-worn, which is known as boulder-clay. Also, laid down here and there, sometimes on mountain tops, we find enormous blocks brought from great distances to the west, as shewn by the rock of which they are made. We also discover all across the country certain remarkable scratchings, and deep indentations on the exposed surfaces of the hardest rocks, all pointing in one direction, at right angles to the broken cliffs. We also note that all heights are rounded and worn, as if ground down by some powerful agent moving over them.

The problem before us therefore is—How are all these appearances to be accounted for, and by what agent or agents were they produced?

It is evident, from the existence of the clay, that the whole region referred to must have lain under water. But water alone, even in a powerful current, could not carry the blocks, and make the deep scratches that everywhere are seen. It is evident that these effects must have been produced by something borne on the surface of the water, of size and hardness capable of doing all this. What hard substance, therefore, can be borne by water, that can carry rocks and leave deep scratchings behind it? Nothing but ice in the form of huge bergs; and a current bearing packs of these on its surface fully satisfies all the requirements of the case. Floating along, of enormous size, these ice-mountains wear down all surfaces over which they move; carry from great distances, and drop as they melt, blocks of every size; dash against and wear down into cliffs all opposing eminences; and leave marks on the rock-surfaces identical in appearance with those everywhere exhibited; while the current that bears them along, deposits in the lower grounds the mud and boulder débris they generate in their onward course. Thus we prove incontestibly that icebergs floated over the district exhibiting these phenomena. But was the climate such as to generate icebergs? This is proved, independently of the above reasoning, by various considerations; amongst others, by the fact, that in the boulder clay in various parts shells are found, called boreal

shells, that could only have lived in an arctic climate, and now live only in the northern seas.

2. *The Existence of Glaciers in Britain.*—In the same way, we can as conclusively prove that these great bergs were broken from glaciers that at that remote epoch filled the upper valleys of the Highlands, to the north and south. This is shewn by such facts as these, which we can but enumerate—the general aspect of these valleys; the striations and polished surfaces pointing always to the highest peaks, whence the ice-streams descended; the rounded rocks with steep sides looking *down* the valleys; the rocky, worn, and broken débris; the moraines or rock-walls driven before the advancing ice, or borne on its surface, and that now run along or across the valleys like ramparts; and other equally striking and conclusive phenomena. Thus we arrive at the undeniable fact, that the British Isles once exhibited in successive periods all the ice-features of Greenland, Norway, and the Alps.

The Rocks as Related to Time.

The Length of Geological Periods, or Geological Time.—In studying Geology, it is necessary to have an accurate notion regarding the nature of the periods spoken of. It is to be strictly observed that in Geology, time cannot be measured by years. When we examine any stratum of rock, with all its enclosed organisms, it is natural to inquire how long this mass of rock took to be deposited. We can judge of this only in the following way. From observation of river-action as at present exhibited, we see with what extreme slowness rock-masses are worn down into sand; how a thousand years make an almost imperceptible change on a boulder, and even on the gravel by the shore. Yet we know that the sandstone before us, often hundreds of feet in thickness, is composed of grains of rock ground down by water-action, transported by rivers to the sea-bottom, and deposited there till other strata were heaped upon it; and that in after-ages the grains united, and were hardened by pressure into the rock we see. What incalculable ages, therefore, must this sandstone bed have taken to be thus formed! The more we think of these slow-working causes, the more are we astonished at the enormous periods of time that must have elapsed before the formation of even the thinnest layer of rock. Geological periods, therefore, are quite indefinite in the matter of *years;* but from various considerations, we can arrive at certain very definite conceptions regarding the length of time required for the formation of the various rock-systems. This inability to assert a definite number of years in regard to any formation, is no defect in the science, for the knowledge of this would add not one item to the conception we

already have of the immense periods presented to our contemplation by geology.

The Relative Ages of Rocks.—When we speak of the ages of rocks, we can do so only by comparison with others. Our ideas on this point are merely relative. We can assert, as we have already done in analysing the rock-sections, that one layer must have been formed before another; or that, after its formation, and before the deposition of a certain other rock, a rise or fall in the strata took place; or that, at a certain point in the series, a volcanic eruption threw up a mass of igneous rock; and make like statements based on comparison of the rocks with one another. Our conceptions, therefore, regarding the connection in age between the various rock-formations are merely relative, one being proved to have taken place before, or after, or during the formation of another.

The Order of the Rock-formations.—By long-continued and widely extended observations in various parts of the globe, based on numberless data of composition, structure, inclination, and fossil contents, geologists have been able to form a definite list of the various rock-formations from the earliest to the most recent, arranged in the order of time. They have divided the whole of the rocks composing the crust of the earth into sections called 'systems,' and these again into 'groups,' in a certain well-defined order—so that when a rock is presented to their observation in any part of the globe, they can state, with more or less certainty, the system to which it belongs, and the period in the past history of the earth at which it was deposited. Regarding these rock-systems, one point is to be very strictly noted. Suppose that we represent the various rock-systems by the letters of the alphabet—the earliest by A, the second by B, and so onwards to the last and most recent, represented by Z. Now, the various rock-systems always stand in this relative historic order; so that the formation indicated by M is always after L, and before N, and cannot occur in any other relation to these two systems, wherever they may be found. At the same time, certain formations, one or more, may be awanting in certain parts of the world, not having been deposited there; so that one or more systems may not be represented in these districts. Thus, L and M may be awanting. What two systems will then be found together? Certainly and unvaryingly, K and N. But here the historic order is not violated, as it would be if N preceded K. The various rock-systems are, therefore, always presented in an unvarying succession in the order of their formation; although in different parts of the globe certain strata, and even whole systems, may not be found.

Classification of the Rocks—Description of the Rock-Systems.

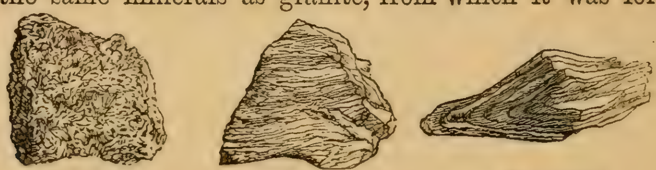
We now proceed to describe, in the order of their formation, the different kinds of rocks that compose the crust of the earth, and their fossil contents. As already said, geologists have divided all the rocks into different classes, according to their relative position and the fossils they contain. The whole of the rocks are divided into twelve great systems, and each of these into separate groups, to which names have been given, more or less descriptive of the strata to which they are applied. These systems we shall describe in order, beginning with the earliest, down to the most recent, giving the appearance and composition of the rocks, the uses to which they are applied, and the fossils they contain. We shall also endeavour to realise the state of the earth at each successive epoch, the scenery then exhibited, and the plants and animals that then enlivened the landscape. Before doing so, it is interesting to ask—

What Rock is oldest and lowest?—What rock is the foundation on which all others rest? On the answer to this question, geologists are not agreed. We know the oldest sedimentary rock; and though the above question were to remain unanswered, the science of geology proper would be as complete as it requires to be. But some approach can be made to an answer. Granite seems to underlie all other rocks; at least, as far as yet ascertained, no other rock has been found under the granite, and this rock is erupted through all other strata; but we cannot assert definitely that this is the primitive or oldest rock, but only that, as far as yet discovered, no other has been found to underlie it. All are familiar with this beautiful variegated rock as used for paving our streets, and as polished for gravestones and hewn into pillars. It has two chief varieties, the gray and the red, according to the prevailing mineral in its composition. It composes the mass of the chief mountain ranges, and forms part of some of the grandest scenes in nature. It is generally considered to be of igneous origin. It shews no stratification, occurs only in great mountain masses, or in veins intersecting other strata, and seems to point to a period in the past history of our globe when it was a great molten ball, with conditions that we can scarcely imagine, so different must they have been from those now existing. But it seems to be undeniable, that before any of the stratified rocks were deposited, and before any life existed, the globe was in a state of molten fusion through intense heat; and that we have before us, in the granite, the remains of that igneous condition, which now exists as a cold, crystallised, variegated rock, containing valuable minerals, and of great industrial value.

I.—Metamorphic System.

Description.—Immediately above the granite, and resting directly upon it, lie the most ancient sedimentary rocks in the long series of formations before the human era. These rocks do not exist now as they were laid down. The whole granite surface seems to have retained much of its heat, at least so much as to have changed the character of the mud at the bottom of the seas, and thus formed the hard crystalline rocks of this earliest sedimentary system. It is from being thus changed or *metamorphosed* by heat that they have received the name of the *Metamorphic System.*[1] They consist of various strata, of which the chief are Gneiss, Quartz-rock, Mica-schist, and Clay-slate.

Gneiss,[2] so named from its thin layers, is a hard crystalline rock, in extremely thin bands, often twisted in a remarkable manner. It consists mainly of the same minerals as granite, from which it was formed, but



Granite. Gneiss. Mica-schist.

Fig. 83.

these are broken and confused. Quartz-rock, as its name implies, is composed of fine grains of quartz. Mica-schist obtains its name from the particles of mica that form its chief ingredient. These three kinds of rocks compose one great group, and, though frequently intermingled, occur in the above order. They are extensively developed in Britain, especially in the Highlands of Scotland, where they form the mass of the mountain ranges, and enter into the grand and beautiful scenery of that picturesque region. With them also occurs limestone, which, having been crystallised by heat, forms beautiful marbles, quarried for various purposes.

Clay-slate is that most useful rock, which, split up into thin layers, forms the familiar blue slates for our roofs, and the slate and slate-pencil used every day in school. There is something very interesting in the thought, that the slates you may now see before you, or may be even now using, and the pencil in your hands, are obtained from the earliest of all our rock-formations, and are formed of the fine sand washed from the primitive granite, but lately cooled down!

Organic Remains.—The Metamorphic rocks, from being the earliest of our rock-systems, are known also as the *Primary* rocks, or those first

[1] From Greek *meta*, change, and *morphē*, form. [2] From Anglo-Saxon *gnidan*, to rub.

formed. Because they seem to contain no fossils, they have also been called the *Non-fossiliferous* rocks ; but this assertion of the absence of organic remains is not to be taken as final, because in them fossils may yet be discovered, as they have been in the upper beds, which have lately been formed into an independent system. The existence also of plumbago in these rocks, the lead-like mineral used for pencils, which is a kind of coal, and may therefore have been formed of vegetable matter, seems to shew the likelihood of future organic discoveries.

Scenery.—Regarding the scenery of this early epoch, we can form only the dimmest conception. After the intense heat of the primitive granite had subsided, and the once molten mass seems to have become hard and solid as we now see it, a system of things appears to have begun, bearing more likeness to that now existing. Granite mountains reared their heads, great seas rolled their billows, while rivers flowed across the plains, conveying to the ocean-floor the débris of the granite continents. Such organic life as then existed, if it did exist at all, has either been totally destroyed by the great heat of the granite surface, or remains yet to be discovered.

II.—Laurentian System.

Description.—Immediately above the Non-fossiliferous Metamorphic rocks lie the lowest of those that contain fossils. These have received the name of the *Laurentian System*, from their great development on the shores of the St Lawrence, in Canada. It was only quite lately, in the year 1863, that these rocks were grouped into a distinct system, from the discovery in them of certain fossil remains in Canada, having previously been reckoned Metamorphic. The Laurentian System consists of certain schists, quartzose rocks, and limestones, all very highly crystallised—only little less so than the Metamorphic rocks. They contain no sandstones or shales, that occur so frequently in higher formations, such of these as once existed having been changed by heat. Even the limestone is unlike the limestones that occur higher up, being very highly crystallised. The rocks, however, are all truly sedimentary, deposited under water, and have received their present aspect mainly through the agency of heat. They are found in Canada, the Hebrides, Ireland, and Norway and Sweden.

Organic Remains.—The discovery of the fossil remains that caused these rocks to be formed into a separate system, was made in Canada, and excited interest amongst geologists, because belonging to a period when organic existence was thought impossible. The organism discovered received the name of the Canadian Eozöon[1] or *Dawn-animalcule*, and

[1] From Greek *ēōs*, dawn, *zōon*, an animal.

consists of minute tubes or cells that are visible only under the microscope. Some still deny that this structure is organic, and regard it as merely a mineral appearance; but these are few. The general opinion now is that here we have the earliest life-remains yet discovered on our globe; and this all the more certainly that worm tracks and burrows were found in 1866 in the same formation. The discovery of these evidences of organic life, so long sought in vain, shews that more minute search may result in other remarkable discoveries, and that in all likelihood the name of Eozöon will be found to be premature.

III.—Cambrian System.

Description.—Immediately above the Laurentian lies a series of slates, schists, and crystalline limestones, called the Cambrian System. It is so named from being first most fully described as it is found in North Wales, which in Roman times was called *Cambria*. The rocks in this series are less changed than the Laurentian, and therefore the remains in them are more numerous and better preserved. They are of great thickness, and are found in Wales, Cumberland, North-west Scotland, Ireland, North America, and elsewhere. Along with the older rocks beneath them, they everywhere form mighty rugged peaked mountains, like those of Wales and the Highlands; and their worn rugged aspect is due to their being so long subjected to wasting influences from their great antiquity. All these earlier rock-formations, from the Metamorphic to the Silurian, are exceedingly rich in mineral wealth, most of the precious metals being obtained from them. Shooting through their hard crystalline masses, we find veins of iron, copper, silver, and gold; and, from the presence of these metals, bare mountain tracts have teeming populations, where even the sheep with difficulty finds its scanty food.

Organic Remains.—The fossil remains are all of the very lowest kinds of life. Sea-weeds, shells of different kinds, and some crustacea, especially one that occurs abundantly in the next formation, called the trilobite, have been discovered. The tracks and burrows of worms, formed in the sand of the ancient seas, may also be seen perforating these hard masses.

Scenery of Period.—During the Cambrian age, quiet seas heaved their waters as now, tenanted with shells and crab-like creatures, while waves rolled on the sandy shores, over which worms crawled, and into which they burrowed; interesting as shewing that creatures had then the same kinds of habits as now, and that what we can see any day along our own shores sends us back to the distant ages when the world was young!

IV.—Silurian System.

Description.—The Silurian System contains rocks less changed by heat than those below, and exhibiting more abundant life. In those already mentioned, the change that has passed over the strata has been so great as to render it difficult to say, with certainty, how the rocks were originally formed, but henceforth all hesitation vanishes. We have slaty sandstone finely laminated, and often exhibiting ripple-marks; conglomerates chiefly of rounded pebbles, clays, and limestones, with corals and other fossil remains, all of great thickness. The system has received the name of Silurian from being very fully developed in a part of South Wales anciently called *Siluria*, and is therefore named from its chief locality. From these rocks are obtained roofing-slates, freestone for building, flagstones for paving and other purposes, limestones, from which lime is got by burning, and valuable ores of lead, copper, silver, mercury, and gold.

Organic Remains.—Parts of the stems and leaves of water-plants and club-mosses, and a few sea-weeds, are found, but all scarce and much broken. No land *animals* have yet been obtained, and though it would be rash to say that they do not exist, everything seems to render this very probable. But marine fossils are numerous and well marked, some of them being very beautiful. We find corals of different kinds, named according to their appearance, such as the sun, star, cup, pipe, chain, spider, and honeycomb corals. One of the commonest forms in the Silurian rocks is a very beautiful curved creature like the plume of a goose-quill, called the *Graptolite*,[1] from looking like a *pen* on the *rock;* some single, others double, some straight, others beautifully spiral. Another very abundant form is the Encrinite, a coral creature more numerous in the Carboniferous System. We find also star-fishes, and numerous shells with single and double valves, some like the periwinkle and cockle being abundant. But the creature that swarmed most in the ancient Silurian seas was the *Trilobite*, so called from its body consisting of *three lobes* or divisions, above which was set its head with large double eyes, still to be found entire. It had various forms, and seems to have been very active, and

Coral. Trilobite.

Fig. 84.—Silurian Fossils.

[1] From *grapho*, I write, and *lithos*, a stone.

was of all sizes, from mere specks to fine specimens ten or twelve feet long. Creatures like the scorpion, with toothed toes, are also obtained, and in the upper beds fishes.

Scenery of Period.—Of the dry land we know little or nothing, except that it did exist, and nourished certain aquatic plants and club-mosses, whose remains were floated down into the great seas. But we can see mighty oceans, in which corals flourished, and encrinites waved their lily stems. Shells were abundant, and numerous creatures gambolled in the bright sun. These seas were fringed by sandy shores, on which worms crawled and left their tracks; gravelly beaches, that have become conglomerates; and great beds of shells, that have given origin to thick limestones. Life gradually assumes more activity, and living forms become more numerous and elevated in the scale of existence as we ascend in the system towards the active period that follows.

V.—Devonian System.

Description.—The Devonian System of rocks has been rendered famous through the writings of several geologists, especially the celebrated Hugh Miller, and is one that in itself possesses the very greatest interest. In early geology, the Coal-measures were considered very important; and as both below and above them a great thickness of red sandstone is found, the rocks above were named the *New Red Sandstone;* while those below, being of course older, were called the *Old Red Sandstone*, or, shortly, the *Old Red.* As these older rocks are extensively developed in Devonshire, this system has also been called the *Devonian* System, a name now more used than the other. These rocks are found also in other parts of Britain, especially in Forfarshire and Caithness, where they are extensively quarried, and in parts all over the world. The name 'Old Red' indicates that the chief rock is a red sandstone, which is used very extensively for building. This also occurs in fine flags used for pavement, generally of a gray colour—the famous Arbroath and Caithness pavements being from this system. The remarkable rock called Conglomerate or 'Plum-pudding Stone,' which looks as if it consisted of a consolidated sea-beach, is also found extensively in this system.

Organic Remains.—There are comparatively few plants found in the Old Red, as compared with the animal remains. We find sea-weeds of different kinds, marsh-plants like our bulrushes, sedges and horsetails, tree-ferns and reeds; but they are neither abundant nor well preserved. Animal remains are numerous, varied, and beautiful. There are many species of corals and shells. The tracks of certain creatures, and deep burrows, sometimes eighteen inches deep and one and a half across, made by large burrowing worms, are frequently found. Many crustaceans are

obtained, one of which is a huge kind of crab, sometimes six feet long, with terrible-looking toothed claws, called the *Pterygotus*[1] or ear-wing. Reptiles are also found, two very large lizards being most frequent.

But by far the most numerous specimens of ancient life are gigantic fishes. These creatures are all covered with hard bony scales, burnished with enamel, with fierce teeth, and great fins armed with long sharp spines, with which they defended themselves or attacked their enemies.

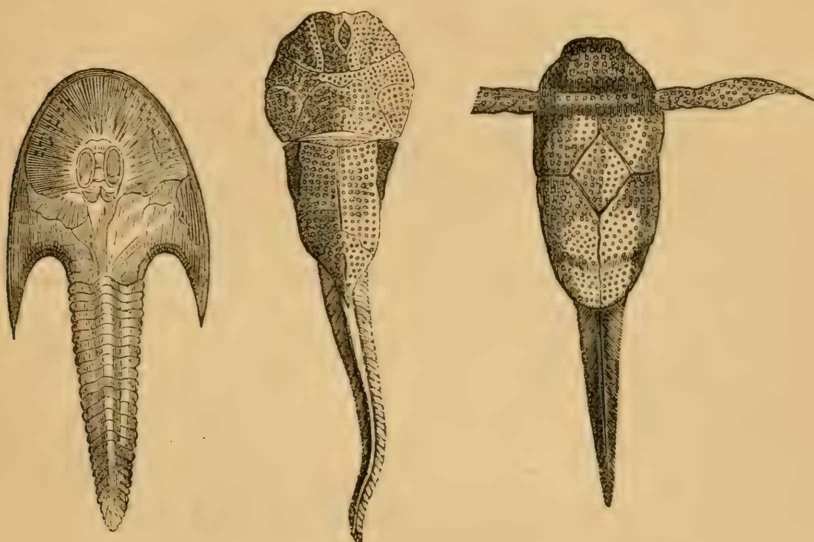


Fig. 85.—Old Red Sandstone Fishes.

These fishes have received different names, according to peculiarities in their structure or appearance, and have been brilliantly described by Hugh Miller, who, when cutting the Old Red Sandstone as a mason, had his attention first drawn to geology by the brilliancy of their scaly armour.

Scenery of Period.—The wide oceans in which the thin fine-grained flags were deposited must have been smooth and tranquil. Round the coral islands that rose in its gleaming waters coursed huge fierce fishes. The sandy shores became the coarser sandstone. Within tide-mark, numerous great crabs lived, and caught their prey in their toothed claws; shrimp-like creatures danced over the sands, and in them worms burrowed; the waves ebbed and flowed, leaving their ripple-marks on the rocks we now see; gravel beaches fringed the shore, where the surges rounded the pebbles and rolled the stones, creating our conglomerates;

[1] *Pteron*, a wing, and *ous*, *otos*, the ear.

and rain-showers fell over the land, and left there the sandy bays pelted with their drops; and forests of sea-weed waved in the green waters and on the rocky reaches; and shells adorned the rocks. Into the seas flowed great rivers, whose banks were fringed with reeds and flags; ferns waved on the hill-side, tree-ferns reared aloft their feathery plumes, and broad-leaved plants clothed the surface of the landscape; while large reptiles roamed through the forests, or crushed the reeds by the river-sides.

VI.—Carboniferous System.

Description.—Above the Devonian rocks lies a series of strata perhaps more generally known than any other, as they afford us what is so necessary to our comfort, the remarkable combustible stone called coal. They receive the name Carboniferous from the fact that they contain coal, although they furnish many other important products. These rocks are found in most regions of the globe; but in none are they more fully developed, compared with the size of the country, than in the British Isles. They consist of sandstones, limestones, shales, clays, ironstone, and coal. The sandstone is of various qualities and colours, some of it very valuable and durable; the beautiful stone of which the New Town of Edinburgh is built being from this system. The limestones are largely developed, and are of the greatest service for building and agriculture. The shales have of late become very valuable, as from them are distilled oils and other substances, including the celebrated paraffin oil and candles. The ironstone is of the very greatest value.

It must not be thought that coal is found only in the Carboniferous rocks. Coal being simply compressed vegetable matter, may be found in any rock-system in which plants are preserved, and is so found in other systems, and often in great abundance. For example, the coal-fields of Virginia, some thirty or forty feet thick, belong to another system, the Oolitic; and coal of various kinds can be obtained, more or less, from most systems.

The same is true of other products, such as limestone, sandstone, and iron, which last, though found in greatest abundance in this system, yet occurs in many others.

The Coal-strata are divided into three great groups—the Upper and Lower Measures, and a thick deposit of limestone, which separates them, known as the Mountain or Carboniferous Limestone. The Upper Coal-measures are also called the True Coal-measures, as they contain the greatest amount of workable coal; the Lower Coal-measures consist chiefly of sandstones and shales. The Mountain Limestone is so called because where it is most largely developed, as in Yorkshire, it rises into hills with great limestone cliffs.

The industrial products of this system are numerous and important. We have coal of all kinds for household purposes and gas; iron, sandstone, limestone, and fire-clay. From the shales are obtained alum and the remarkable paraffin oil; and so abundant in America and elsewhere is

Fig. 86.—Carboniferous Plants.

this ancient oil, that when the earth is bored, a flood of it issues forth yielding thousands of gallons daily.

Organic Remains.—The organic remains found in this system are very abundant and remarkable. Plants are numerous, varied, and beautiful.

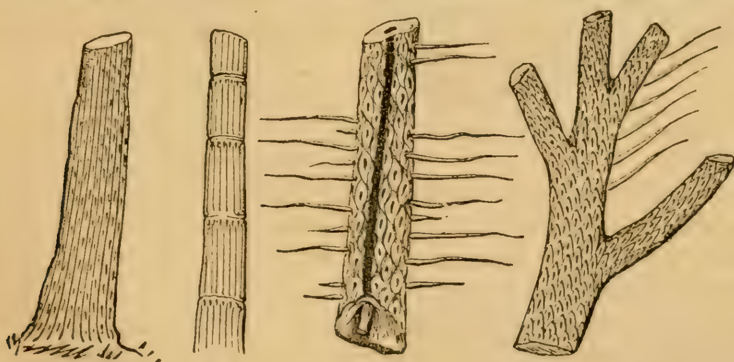


Fig. 87.—Carboniferous Trees:
1, Sigillaria; 2, Calamite; 3, Stigmaria; 4, Lepidodendron.

Ferns are found with the most perfect fronds, as distinctly traced upon the rock as a modern dried fern on the pages of a book. We find also large and beautiful club-mosses exquisitely exhibited. But the most luxuriant and beautiful of all are the great pine-like araucarias, the tree-ferns, and tall reeds that grew in boundless swamps and jungles along

the banks of the rivers that swept in mighty volume to the carboniferous sea. We see the lepidodendron[1] or scale-tree, with its pine-like leaves, beautiful scaly bark, and great cones, from which the seed of the ancient pine may be gathered in hundreds to this very day; the sigillaria[2] or seal-tree, with its seal-stamped trunk and great pitted and branched roots, long thought to be a tree of a different species; calamite[3] or reed, rising high into the air, like the bamboo, with its joints and leafy branchlets; and many more, equally beautiful and well preserved.

The animal remains found are numerous and strange. Corals are abundant and beautiful; but no sea-creature was more common than the encrinite, which rose on its long jointed stalk, bearing its cup-shaped body, with its hundred fingers, that moved on all sides to secure its prey, like the anemone of our own seas. The remains of encrinites are in some places so abundant as to form thick beds of limestone, called Encrinital Limestone; and when these, hard as marble, are polished, they present a most beautiful surface, through which is seen the exquisite carving of the encrinite stars. The little joints of the stems are often found detached, with a hole through the centre; these are known as Fairy Beads and as St Cuthbert's Beads; and when strung together, were used as a rosary, and no more beautiful ornament was ever hung round the neck of a saint. We also find star-fishes and sea-urchins; and the spines of the latter may be seen running through the limestone like threads of burnished silver. The shells are very numerous and varied; univalves and bivalves of both sea and land being everywhere found, and some of these can hardly be distinguished from shells gathered on our own shores, so perfect are they in form, colour, and structure. They may be detached from the rock, and collections made of them as easily as of modern shells. We find also crustaceans of different kinds; and the last trilobites are found in the Coal-measures. Fishes are numerous and formidable, but less so than in the Old Red Period. Reptiles in both salt and fresh water have also

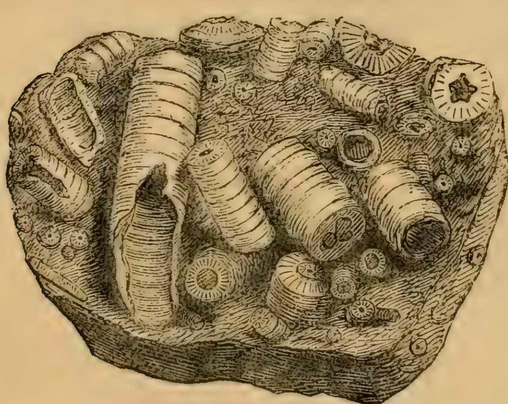


Fig. 88.—Fragment of Encrinital Limestone.

[1] From Latin *lepis*, a scale, and *dendron*, a tree.

[2] From Latin *sigilla*, a seal.

[3] From Latin *calamus*, a reed.

left their remains, and their footprints may be seen on certain sandstones as distinct as if made but yesterday on the soft mud.

Scenery of the Period.—In this remarkable period there stretched wide shallow seas, in which sported huge sharks, and whose waters washed the shores of many islands, guarded by great coral reefs, where the beautiful encrinite spread its waving arms. By the shores lived numerous shells, often in immense beds, that now form the mussel-band of the miner; and into these seas flowed Amazonian rivers, bearing into the deep the spoils of their wooded and reedy shores. By their wide estuaries and along their banks lay extensive impassable swamps and jungles, in which gigantic reeds, calamites, and tree-ferns flourished in tropical luxuriance, and amidst these lurked fierce crocodiles and mighty lizards, which have left their footprints on the yielding mud. The whole surface of the land was covered with tall pines and tree-ferns; the seal-palm, the scale-tree, and star-leaf shot into the air in impenetrable thickets, shaking their numerous cones in the breeze, while the hum of insects might be heard in their still recesses. In the distance might be seen towering snow-peaks, and here and there the smoke of the volcano, the existence of which was felt in the numerous earthquakes that shook the ground.

VII.—Permian System.

Description.—Immediately above the Carboniferous strata, we find certain strata that used to be called, as already explained, the *New Red Sandstone,* in contrast with the rocks below them, called the Old Red Sandstone. This New Red Sandstone series has been of late more thoroughly examined, and found to consist of two distinct portions, whose remains are so different that the series has been formed into two distinct systems, known as *Permian* and *Triassic.* The name Permian has been given to the system we now describe, from being developed very extensively in Perm, a province in the north-east of Russia. These rocks are found in many parts of the world, and largely in Scotland, England, Germany, and Russia. They consist of red and whitish sandstones, shales, and limestones, containing much magnesia. The rocks are remarkably variegated in colour, so much so as to be called the Variegated System; while the limestone receives the distinctive name of the Magnesian Limestone. As the old name suggests, the sandstone is of a reddish hue, and the two chief rocks, therefore, are the Red Sandstone and the Magnesian Limestone. The sandstones are used for building, as are also the limestones, which have been employed in the construction of the Houses of Parliament. Copper is also extensively obtained from one of its shales in Germany, and also lead and zinc, but not very abundantly.

Organic Remains.—The plants resemble greatly those of the Coal-

measures. We find sea-weed, fine-leaved ferns, tall calamites, and reeds, great pines with cones, tree-ferns, and palms like the modern fan palm. The animal remains are not nearly so numerous as in the coal rocks. There are sponges, corals, sea-urchins, and beautiful shells. We also find fishes like those of the Coal-measures, and the Permian is remarkable as the system where the ancient form of tail, in which the spine of the fish was continued into the upper lobe of the tail, becomes extinct, never to appear again. The reptiles of this system are numerous and perfectly developed, some of them being of gigantic form. Their footprints, in particular, are remarkably abundant and large, and from these alone, the whole animal has been constructed by learned men, the truth of their drawings being proved by subsequent discovery of the entire creature. Even pouched animals, like the kangaroo, are found in the American Permian, thus shewing a gradual but slow approach to modern life forms.

Scenery of Period.—The Carboniferous Period was remarkable for the great activity of volcanic agents, but this period seems to have been comparatively tranquil in this respect. The rivers carried in their waters much iron, as they did in the Old Red Period; the seas appear to have been shallow, bearing in solution magnesia and salt, while animal and vegetable life seems scarce, as compared with other epochs. From the existence of a rough conglomerate in the west of England, it has been ably argued that the greater part of the period was one of glacial action, with icebergs bearing blocks and rounded *débris;* and if this was the case, we have a conclusive explanation of the scarcity of life during this period.

VIII.—Triassic System.

Description.—The upper part of the old system, known as the New Red Sandstone, has received the name *Triassic,* which means *triple,* from being found in Germany in three distinct groups, of which the first and third alone exist in Britain.

The system contains sandstones of different colours, shales, and conglomerates; but the distinguishing product is rock-salt. This occurs in beds of from seventy to one hundred feet thick in Cheshire, whence we obtain salt for daily consumption. Salt-springs also abound in salt districts, being formed by the issuing of water through the salt rocks below. The Triassic rocks are found in patches in the British Isles, but extensively on the continent of Europe and in America.

Organic Remains.—The organic remains are very scanty, especially when compared with the exuberance of life in eras before and after. Plants are rare both in number and species. We find horse-tails, calamites, and ferns. The gigantic trees of the Coal-measures no longer exist,

and we have instead short palm-like trees, like the modern cycas. The vegetation is mostly of a tropical kind.

Animals are far from abundant, but are more numerous than the plants. We have no corals, few encrinites, and bone-plated fishes are rare. There are a few shells, some crustaceans, and several great shark-like fishes. Reptiles, however, are numerous and of gigantic size. One brute in particular, called the *Labyrinthodon*, from the *labyrinth*-like structure of a section of its *teeth*, is an uncouth, frog-like creature, with great staring eyes, and immense toothed jaws. The most abundant remains in the Triassic are the great footprints of large lizards. These are found in Scotland, but are so numerous in America, that above one hundred species of creatures have been distinguished, as indicated by these footprints. Huge birds, too, were numerous, and have also left their marks

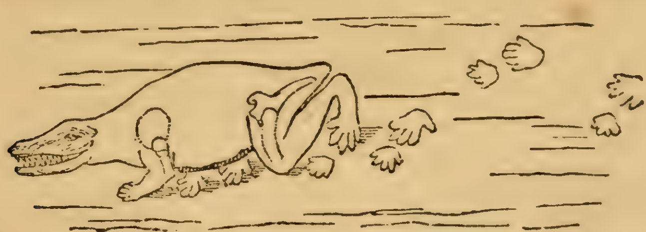


Fig. 89.—Labyrinthodon.

upon the rocks. These rocks furnish the earliest evidences of warm-blooded mammals.

Scenery.—The scenery of the old Triassic age is peculiar, and we can form but a dim notion regarding it. We can easily see that the seas were shallow with bordering lagoons, in which the salt waters were evaporated in the strong sun-rays, and left the salt-beds that are now of such service to us. By the muddy rivers lived great crocodiles, that lurked amid the reeds and pines, and fed on shell-fish and crustaceans, and left their footprints on the yielding mud, while on the dry plains above grew plants adapted for an arid soil and tropical climate.

IX.—Oolitic System.

Description.—We have now arrived at a remarkable epoch, whose remains, abundant and wonderful, have been more fully investigated and described by celebrated men than perhaps any other. We begin also a new epoch in geologic history; the forms of life, habits, and scenery are more like those of our own times, and can therefore be restored with the greater certainty.

The term *Oolitic* is applied to a series of rocks which in England form three distinct groups—the Lias, Oolite Proper, and Wealden.

The Lias is the oldest, and receives its name, a corruption of *liers* or *layers*, from the thin variegated beds of which the rocks are composed, and which present a remarkable ribbon-like appearance not easily forgotten. The Oolite[1] is above the Lias, and is so called from the rock being greatly composed of small round grains like the eggs of the cod, so that it signifies the *egg-rock*, being called also *roestone* and *peastone*, according to the size of the particles. These strange granules consist almost entirely of lime or grains of sand coated with lime. The *Wealden* is the highest rock in the series, and receives its name from being developed largely in the *Weald* in Kent and Sussex. The name *Oolitic* has been applied to the whole system, because the egg-structure is common to all the rocks in the series, although the term *Jurassic*, from its being largely found in Mount Jura, is given to it by some geologists.

The Oolitic system consists of a series of sandstones, limestones, sometimes so hard as to be used as marble, shales, and clays, while ironstone bands, coal, lignite, and jet are abundant. The sandstones are useful as building-stone, the celebrated Bath and Portland stones, so much used in

Fig. 90.—Oolitic Plants:
1, Palm; 2, Tree-fern; 3, Cycas; 4, Pandanus; 5, Zamia.

London and the south of England, being varieties. The limestones are burned for agricultural purposes; the clays are extensively developed, and receive different names in different parts, and yield alum, sulphur, and fuller's-earth. Ironstone is abundant and good, and furnishes a great part of the iron of Yorkshire, being eleven feet thick. The coal is

[1] From Greek *ōon*, an egg, and *lithos*, a stone.

workable and abundant, which disproves the notion too prevalent that coal can be obtained only from the Coal-measures. Lignite is a less hard variety of coal, and the jet, which is only a crystallised coal, yields the beautiful jet of Whitby, so much used for ornaments.

Organic Remains.—The remains of plants and animals are so abundant, that their enumeration and description would fill volumes, and we can merely roughly indicate some of their wonderful forms.

Vegetable life was abundant, requiring a warm climate like that of Australia. We find sea-weeds, beautiful tree-ferns, lily-like leaves, palms like the pandanus, and pines like the araucaria and yew. The clays that occur were the very soil on which those ancient forests grew, and in some of them, known as 'dirt-beds,' the roots are seen in natural position, with part of the trunk broken over, while the tree itself lies close by, as if cut down by the woodman but yesterday.

The animal remains are abundant and remarkable. We find sponges, exquisite star-corals, beautiful encrinites, sea-urchins, worms, and lobsters. The shells are very beautiful and varied, the most remarkable being the ammonite, of which there are one hundred and thirty species, and the nautilus. Gigantic cuttle-fish floated and spread their black ink through the oolitic seas. Fishes were numerous and large; huge plated sharks devoured their prey, their very names telling terrible things, such as 'Strong-tooth,' 'Sharp-tooth,' and 'Great-jaw:' tortoises also floated on the summer seas.

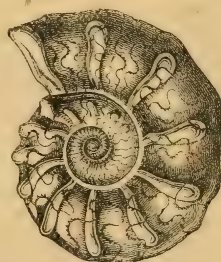


Fig. 91.—Ammonite.

But the most striking remains are those of reptiles, so numerous, strange, and uncouth, that the Oolite has been designated the 'Age of Reptiles.' We find enormous skeletons, some of them thirty feet long, of large lizards and crocodiles, all being more or less strange and terrible.

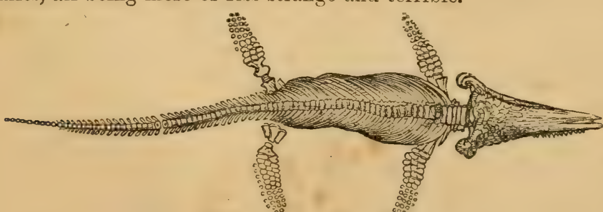


Fig. 92.—Skeleton of the Ichthyosaurus.

In these rocks, too, a most interesting discovery has lately been made, that of the earliest feathered creature—a real bird—in which the bones,

claws, and full-spread plumage are finely seen. The remains of the earliest warm-blooded animals have also been found—a kind of pouched creature like the kangaroo.

Scenery.—The scenery and animals of the Oolitic Period resemble, to a remarkable extent, those of Australia, both in vegetable and animal remains. The land and water went through many changes during this long period. In the Lias times, the seas were deep and tranquil; under the Oolite, exposed coral beaches were dashed by great breakers, that have left their work in broken shells and marls; while the Wealden seems to have been the carried deposits laid down in the estuary of a mighty river, that rolled into the sea in what is now the south of England; and the present icy lands of the arctic regions were covered with the vegetation of a warm climate, which now appears as Oolitic coal strata.

X.—Chalk or Cretaceous System.

Immediately above the Oolite lies a system in which the chief rock is the well-known substance chalk, and which has hence received the name of the *Chalk*, or, what is the same thing, *Cretaceous*[1] System. In this system, other rocks also occur, chalk-marl or blue-clay, known by the local name of *Gault* or *Golt;* thick beds of green-coloured sand, called *Greensand;* and, embedded in the chalk, nodules of flint, which when less pure is called *Chert;* and coal, in Vancouver's Island. The chalk is used for many purposes: when it is burned, it forms a useful lime; when hard enough, is used for building-stone; and when crystallised, forms a fine white marble. The flints are an important ingredient in china, porcelain, and glass, and from the sands we obtain fuller's-earth. The whole system has been generally divided into two groups, the lower being called the Greensand, and the upper the Chalk.

Organic Remains.—The plant-remains are rare and imperfect, and seem to have been all drifted. Leaves of different kinds, palms, fruits, cones, and bits of pines have been discovered. Animal remains, however, are very numerous, and most beautifully preserved. We find sponges, corals, sea-urchins, complete in form and structure, beautiful star-fish, numerous crustaceans, and varieties of the lobster tribe. The shells are plentiful, and exquisitely beautiful in form and even in colouring, and are the finest fossil preservations found in any system—including splendid ammonites and nautiluses, and hundreds of other species, whose mere names would fill pages. Fishes are not numerous, but are well preserved, and, as in other systems, are named from peculiarities in form or structure, such as the 'twisted tooth,' the 'wrinkle tooth,' 'thick tooth,' and such

[1] From Latin *creta*, chalk.

like. Reptiles are also found similar to those in the Wealden. Bones of birds have been discovered, as also bones of what seems to be a species of monkey.

Scenery.—The Chalk series appears to be wholly a marine deposit. The land we know little or nothing of; sufficient, however, to shew that it was clothed with vegetable life, as in other periods, but little to picture its appearance. Over it, huge Wealden reptiles sought their prey, birds flew, and great apes swung from tree to tree. But the ocean swarmed with varied life, mild sea-breezes blew, and smiling sunbeams sparkled upon its waters ; for the climate was warm, as shewn by the corals, reptiles, and monkeys. In the tepid waters lived numberless fishes and shells, and on their surface the nautilus spread its coloured sail.

The origin of chalk is a problem not yet satisfactorily settled, but the generally received opinion is, that the shores were fringed by coral reefs, which the dashing waves gradually wore down into fine powder, as they still do in tropical seas, while millions of shell-fish teemed in its waters, and left their white shells as an impalpable sand, that, under the microscope, shews the tiny houses of the old inhabitants as perfect as on the day they died. Flint seems mostly to consist of concretions round sponges, corals, and other substances, and may be found at any epoch, and occurs in many other formations besides the Chalk, though there in greatest abundance.

XI.—Tertiary System.

We have now arrived at a new epoch in the history of the rocks, known as the Epoch of Recent Life. Henceforward, the plants and animals bear not only a close resemblance to those now existing, but a great proportion of them are identical. We discover real exogenous trees, the same corals, crustaceans, and shells, equal-lobed fishes, birds, and mammals of existing families—and all these not only more numerous than hitherto, but also more perfectly preserved. The name given to this system is a relic of the names used in early geology, when all rocks were divided into Primary, Secondary, and Tertiary. In the Tertiary System, two great periods are easily distinguishable : 1. The *Warm Period;* 2. The *Cold Period.*

1. The Warm Tertiary Period.—This system exhibits clays, sands loose or hard, gypsum or plaster of Paris, and marls. The only true rock is limestone, made up of innumerable little shells, so numerous that the stone, which is extensively found throughout the world, is named from its *coin*-like shells, nummulitic.[1] The limestone is burned for various purposes ; the clays are extensively used ; the harder sands are employed for

[1] From Latin *nummus*, a coin.

building; and amber is also found. The strata occur exclusively in patches known as *basins*, the London and Paris basins being the most important.

Fossil Remains.—The remains are both numerous and important. Of plants, there are few marine specimens, as these were too tender to be preserved. We find, however, mosses, palms, ferns, leaves, fruits, seeds of different kinds, and whole pods of pea-plants. We have real exogenous timber, with specimens of fine palm, cypress, and fir.

The animals resemble or are identical with existing species, and the Tertiary System has been divided into periods according to the percentage of life-remains. We have corals, star-fish of the same species as those existing, and the shells are very beautiful, finely preserved, and scarcely distinguishable from those to be gathered on our present shores.

Among the fishes, we find various species of the shark, ray, sturgeon, sword-fish; and of fresh-water kinds, the perch and the carp. Among the reptiles there are the crocodile and alligator, and the turtle. Birds are numerous, one specimen found in the Paris basin being gigantic. Mammals are found of every existing order, amongst others the whale, elk, stag, antelope, camel, lama, tapir, hog, rhinoceros, hippopotamus, beaver, hare, squirrel, monkey, elephant, horse, tiger, and hundreds of others. So numerous are these remains in some parts, that one rock in Norfolk is known as the *Mammaliferous Crag.* But the most remarkable of the ancient animals are the huge monsters whose skeletons, carefully reconstructed, may be seen in the British Museum, some of them above 10 feet high, and 20 feet long. The most wonderful is the mammoth, with two great tusks like an elephant. Others are the dinotherium[1] or 'fierce wild beast,' the megatherium[2] or 'great wild beast,' and the mastodon. In different parts of the world, and in many places in England, remarkable caves are found filled with bones of various animals in clay or sands, known as 'bone-caves.' These caves have some of them been the dens of savage tigers and other brutes, the bones of their prey being still found; some the abodes of different creatures at different times who have lived and died there; while others have had their contents washed into them by floods.

Fig. 93.—Dinotherium.

Scenery.—During this period shallow seas rolled under a genial sun, in

1 From Greek *deinos*, terrible, and *thērion*, beast.
2 From Greek *megas*, great, and *thērion*, beast.

which low islands rose crowned with palms, while the savage shark and sword-fish swam in the surrounding waters; the elephant ranged through the tall groves on shore; the hippopotamus wallowed in the fresh-water lakes; the rhinoceros crashed through rank jungles; the mastodon, mammoth, and tapir trod in forests of palm; and the wild ox and buffalo roamed over wide grassy prairies.

2. THE COLD TERTIARY PERIOD.—Immediately above the strata just described, with these strange organisms that speak of a warm climate, are found remarkable accumulations of sand, often found pure in hillocks; gravel, and clay interspersed with rounded worn boulders, known under

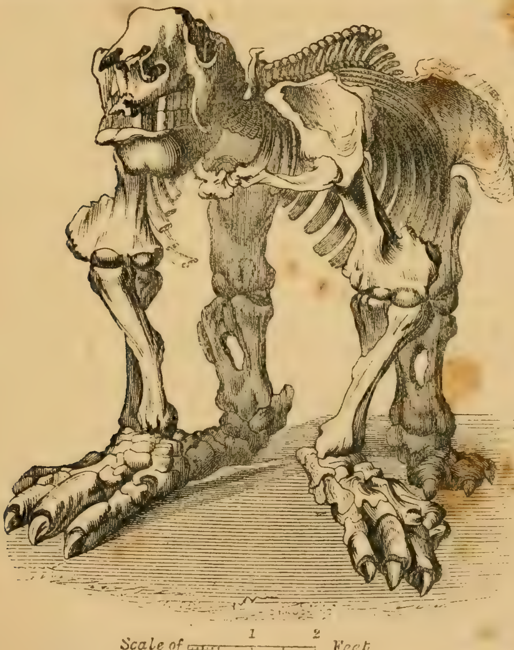


Fig. 94.—Megatherium.

the general title of the 'Boulder Clay,' some of the boulders being of enormous size. From various phenomena, as shewn in a former chapter, it has been proved that the climate became arctic in character, and our country and others enveloped from shore to shore in a vast ice-sheet, like the Greenland of to-day. From the ends of this huge ice mantle, immense masses broke off and floated away as icebergs. By and by, however, the

climate became milder, and Britain looked like Norway and Iceland, with glaciers on the higher grounds, reaching here and there to the sea. Gradually the great ice-fields melted away under the rays of the genial sun, and our country looked like the present Switzerland, till at length the last glacier disappeared from the highest hills. The effects of all the wear and movement of these ice-masses, whether grinding down the land or grating on the floor of the ocean, or dashing against opposing islands, are seen in the thick clay and sand deposits everywhere around us, enclosing worn stones and gravel; the scratched and rounded rock-surfaces often bright and smooth as polished marble; the 'erratic boulders,' perched on our hill-tops and plains; and the general wavy outline of all higher ground throughout our land. This glaciation has been ascertained to extend over the whole of Northern Europe and America, and round the shores of the Antarctic Ocean.

XII.—Quaternary or Recent Period.

We have now reached the last of the great geological epochs, during which sea and land, plants and animals, have remained little changed from what they are now. This last system has been variously named the *Post Tertiary*, *Quaternary*, or *Recent*.

The whole system may be divided into two chief periods:

1. *The Prehistoric*, or that before history was written.
2. *The Historic*, or that since history was written.

During the whole epoch, there is little or no solid rock, the whole deposits consisting of clay, sand, gravel, mud, peat, and the like.

Of *prehistoric* deposits, we find such remains as these: plants of all kinds, all common shells and corals, and common animals, with a few now extinct, such as the long-fronted ox, the gigantic Irish deer—a creature ten feet high to the top of its horns—the elephant, rhinoceros, hyena, bear, and mammoth, besides human remains in bones, canoes, ashes, dwellings, and weapons.

In *historical* times, we find similar remains, but the deposits are comparatively small; and the plant and animal remains are almost solely those now existing in each country. Men have left traces of themselves in buildings, coins, implements, weapons, and works of art; while peat-bogs have been formed, forests have been submerged or cut down, and considerable changes in sea-level have taken place.

Since the glacial epoch, a continuous series of changes has been going on without intermission, accomplished by various causes and in various ways. The land has changed its level several times both by elevation and depression, the sea thus alternately encroaching on and retiring from the land. Whole countries have been gained from the ocean, such as the Fens

in England and the greater part of Holland; old beaches may be distinctly traced, with their cliffs, shores, and shells far above sea-level; whole forests have been submerged, whose old trunks and fruits are thrown up by every storm; and huge accumulations of sand, blown or washed, have been found along its shores. Rivers have been depositing new matter under the ocean at their mouths, increasing the land by the formation of deltas, sometimes hundreds of miles in extent, laying down fine carse-land along their banks, that now forms the richest soil of the farmer, and leaving terraces far above their present level, to mark their former beds. Many lakes have been formed, others are gradually silting up from the earthy matter brought down by rivers, while some have become quite dry and are now waving with corn. Animals have been busy forming new islands and continents, as in the Pacific, where the coral insect leaves its skeleton to form the nucleus of future islands; birds have deposited guano; and myriads of microscopic creatures cover the floor of the ocean, some of the earths now existing being so full of these as to be used by savage tribes as food; and igneous agencies have been and are as active as in the olden times in changing the land and throwing out vast deposits of lava and ashes.

Man.—It is an interesting question how far back man extends into these geologic eras, and this important inquiry has of late years received great attention. Striking results have also been arrived at. It seems to be indisputably proved that man existed as far back as the great glacial period, at the close of the Tertiary epoch, and that he was contemporary with the hairy rhinoceros, mammoth, woolly elephants, and other gigantic creatures now long extinct, which he no doubt hunted as he now does the fox and the deer; and at a period when Britain was united to France, where now the sea flows in the Straits of Dover, his bones have been found in the same deposits with these animals. But this subject is but in its infancy, and it would therefore be unwise to make positive statements where our data are insufficient. Enough has, however, been discovered to shew that men have lived with strange denizens for many ages, and under very different conditions, in our own quiet land.

Fig. 95.—Encrinite.

ROCK FORMATIONS.

No.	Systems.	Reason of Name.	Characteristic Rocks.	Characteristic Life.	Great Periods.	
I.	METAMORPHIC.	From *change* in strata.	Slate and gneiss.	Non-fossiliferous.	Hypozoic or Lifeless Period.	
II.	LAURENTIAN.	From being developed on the *St Lawrence.*	Eozöon limestone.	Canadian Eozöon.	Palæozoic or Ancient Life Period.	Palæozoic or Great Ancient Life Cycle.
III.	CAMBRIAN.	From being developed in *Cambria* or N. Wales.	Slaty rocks.	Lower crustaceans.		
IV.	SILURIAN.	From being developed in *Siluria* in S. Wales.	Slaty rocks with rich ores.	Corals and shells.		
V.	DEVONIAN.	From being developed in *Devon.*	Old red sandstone.	Plated fishes.		
VI.	CARBONIFEROUS.	From containing *coal.*	Coal and iron.	Exuberant vegetation.		
VII.	PERMIAN.	From being developed in *Perm* in Russia.	New red sandstone and limestone.	Last unequally-lobed fishes.		
VIII.	TRIASSIC.	From consisting of *three* groups.	Salt.	Tropical—great foot-prints.	Mesozoic or Middle Life Period.	Neozoic or Great New Life Cycle.
IX.	OOLITIC.	From *egg*-grained *rocks.*	Egg-grained rocks.	Huge reptiles.		
X.	CRETACEOUS.	From containing *chalk.*	Chalk.	Chiefly marine.		
XI.	TERTIARY.	From being the *third* of the old geologic systems.	Clay.	Most existing species.	Cainozoic or Recent Life Period.	
XII.	RECENT.	From being *recently* formed.	Peat.	Man and existing animals.		

Geological Map of the British Isles.

Geology compared to History.

'Geology is intimately related to almost all the physical sciences, as history is to the moral. A historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge by which any insight into human affairs, or into the moral and intellectual nature of man, can be obtained. It would be no less desirable that a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to organic and inorganic nature. With these accomplishments, the historian and geologist would rarely fail to draw correct philosophical conclusions from the various monuments transmitted to them of former occurrences. They would know to what combination of causes analogous effects were referrible, and they would often be enabled to supply, by inference, information concerning many events unrecorded in the defective archives of former ages. But as such extensive acquisitions are scarcely within the reach of any individual, it is necessary that men who have devoted their lives to different departments should unite their efforts; and as the historian receives assistance from the antiquary, and from those who have cultivated different branches of moral and political science, so the geologist should avail himself of the aid of many naturalists, and particularly of those who have studied the fossil remains of lost species of animals and plants.

'The analogy, however, of the monuments consulted in geology, and those available in history, extends no further than to one class of historical monuments—those which may be said to be *undesignedly* commemorative of former events. The canoes, for example, and stone hatchets found in our peat-bogs, afford an insight into the rude arts and manners of the earliest inhabitants of our island; the buried coin fixes the date of the reign of some Roman emperor; the ancient encampment indicates the districts once occupied by invading armies, and the former method of constructing military defences; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. This class of memorials yields to no other in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from all suspicion of misrepresentation. We may be deceived in the inferences which we draw, in the same manner as we often mistake the nature and import of phenomena observed in the daily course of nature, but our liability to err is confined to the interpretation, and, if this be correct, our information is certain.'—SIR CHARLES LYELL.

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